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(ARI/R-88-5102) ANTENNA PATTERN STUDY Final Report (Applied Research Corp.) 62 p

N89-12790

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H2/32 0158873

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ARI/R-88-510Z

Prepared for:

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ANTENNA PATTERN STUDY

FINAL REPORT

JULY 15, 1988

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1.0 INTRODUCTION

Prediction of antenna radiation patterns has long been an important function in the design of command, communication and tracking systems for rocket vehicles and spacecraft. An acceptable degree of assurance that a radio link will provide the required quality of data or certainty of correct command execution must be acquired by some means if the system is to be certified as reliable. Two methods have normally been used to perform this function: (1) Theoretical analysis, based on the known properties of basic antenna element types and their behavior in the presence of conductive structures of simple shape, and (2) measurement of the patterns on scale models of the spacecraft or rocket vehicle on which the antenna is located. Both of these methods are ordinarily employed in the antenna design process.

The rigorous mathematical treatment of electromagnetic scattering processes has been successfully applied to only a few simple geometric shapes, and has not, until recent times, offered a feasible means for solving the problems that are presented by the large and complex structures which often influence the pattern of an antenna mounted on a launch vehicle or a spacecraft. Consequently, antenna pattern prediction has relied heavily on measurements performed on antenna pattern ranges. The carrier vehicle dimensions are scaled by a factor which enables a model to be constructed that can be accommodated on the pattern range. The antennas must be scaled by this same factor. When the vehicle size is such as to require a very high scaling factor, fabrication of model antennas which perform in the same way as their full-scale counterparts may become very difficult because of their extremely small size. Operating frequencies have continually increased as transmitting and receiving technology has been gradually extended into higher and higher frequency ranges. During the same time period, the sizes of launch vehicles and spacecraft have continued to increase. The latter trend has necessitated continually increasing scale factors to enable a vehicle model to be accommodated on an antenna pattern range. These factors, when applied to many microwave antennas, make the construction of a model antenna impractical.

Fortunately, recent years have brought considerable progress in two fields related to this problem:

1. Significant developments and improvements have been made in analytical methods for solving problems in electromagnetic scattering.

2. Computer technology has progressed at a phenomenal rate.

The combination of these two factors has produced a growing capability to reliably predict the patterns produced by complex structures by mathematical computation, and at a reasonable cost.

The purpose of this task is to identify those computational codes which will enable antenna design personnel of the George C. Marshall Space Flight Center to perform antenna pattern computations for several applications involving the use of antennas on physically-complex structures and to facilitate the use of these codes by the incorporation of such supplementary software as may be necessary.

Two computer codes have been identified as being best-suited to the current needs of the MSFC at this time. These codes have been examined and tested and are recommended for use by MSFC. Both codes were developed at the Ohio State University. One is based on the use of the Geometrical Theory of Diffraction and the other is based on use of the Method of Moments. They are considered to be complementary, inasmuch as the GTD code is suitable for use in problems involving electrically-large scattering structures, while the MM code is useful for electrically-small scatterers.

2.0 SURVEY OF EXISTING CODES

A survey was performed to identify such scattering codes as might be suitable for performing the type of computations required in the antenna design work at the Marshall Space Flight Center. Discussions were held with several personnel who are authoritative in the field of electromagnetic scattering theory. These discussions led to a general conclusion that most computer codes that have been written to solve the problems of interest fall into one or more of the following categories:

1. It is company-proprietary and thus not available.

2. Little or no documentation is available for other users. (It is used by the people who wrote it)

3. It is written to solve only certain types of problems.

4. It is not yet ready for release.

Inquiries regarding specific codes confirmed the above conclusion.

The two recommended codes were found to have the following advantages:

1. The codes were readily available to qualified applicants.

2. They are general enough to be used for a wide variety of applications.

3. They are exceptionally well documented.

3.0 CAPABILITIES AND LIMITATIONS OF THE SELECTED CODES

The two recommended codes, NEC-BSC and ESP3, are based on two entirely different analytical processes. Thus, their strengths and weaknesses are quite different. The NEC-BSC code is especially suited to the solution of scattering problems which involve electrically-large structures and in which the scattering bodies can be approximated as assemblies of flat plates and elliptic cylinders. However, it is not well suited to the treatment of electrically-small scattering bodies or scatterers which are separated by very small distances as measured in wavelengths. Also, it lacks the ability to treat certain scattering mechanisms and includes only flat plates and elliptic cylinders as basic model shapes. The ESP3 code, on the other hand, is well-suited to solve scattering problems which involve electrically-small bodies. Scattering centers which are electrically close together do not present any difficulty. Its method of solution enbodies all scattering mechanisms. Its chief limitation is its large memory requirement and long run times. These features are related to the size and geometric resolution of the scattering body (or bodies), so that use of the code is practical only for scattering bodies of about three wavelengths across or smaller.

4.0 DESCRIPTIONS OF THE SELECTED CODES

4.1 NEC-BSC

This code was developed at the Ohio State University and was released for use in December, 1982. It is based on the use of the Uniform Theory of Diffraction, an augmented version of the Geometrical Theory of Diffraction first introduced by J.B. Keller of New York University in the 1950s. Keller's original technique offered a simple and efficient means for mathematically representing the individual scattering mechanisms that collectively comprise the scattering properties of a body. It enabled the user to model the scattering body as a set of basic geometric shapes and to apply the mathematical relations between the incident fields and the scattered fields that had been derived for each basic shape. The total scattered field could then be found as the complex sum of the fields scattered by all of the basic elements. The GTD method of analysis had two significant advantages:

(1) The amount of mathematical computation required was relatively modest; thus a computer code based on this method would not impose high demands on the machine to be used, nor would it result in long run times.

(2) The use of this method provides some insight into the nature of the scattering process taking place in a particular problem. This advantage results from the fact that the scattering process is divided into a set

of individual scattering mechanisms, each of the mechanisms being related to some geometric property of the body. The effects of the individual mechanisms may be examined separately.

Despite its attractive advantages, the GTD possessed some deficiencies which affected its validity under certain conditions. Probably the most important of these deficiencies related to the so-called shadow boundaries that were associated with diffraction by the edge of a conducting body. The GTD is based on a ray-optics concept which treats electromagnetic waves as rays, or straight-line segments which emanate from one point and which may terminate on another point. When the ray-optics model is applied to the conducting edge mentioned above, two angles exist at which the value of the diffracted ray abruptly changes. It assumes a double value at each of the angles. Clearly, this result does not represent reality.

The shadow-boundary problem was solved several years ago by R.G. Kouyoumjian and P.H. Pathek of Ohio State University. They derived a transition function which, when combined with the original Keller expressions for calculating diffraction, resulted in an equation which produces a diffraction value that varies smoothly through the transition regions. It has been shown that this function properly represents the diffraction mechanism that operates in the transition region.

Other refinements have been added to the GTD over the years. Expressions have been derived to represent diffraction mechanisms associated with curved edges and curved surfaces, including the contributions of creeping waves. The modern version of the GTD, incorporating these improvements, is known as the Uniform Theory of Diffraction, or UTD.

Many, but not all, of the known diffraction mechanisms are incorporated in the NEC-BSC code. Those which are included are associated with diffraction by the surfaces and edges of finite-length elliptic cylinders, flat plates and the wedges formed by the joining of flat plates. The scattering mechanisms which are computed in the NEC-BSC code are:

- o Singly reflected fields
- o Doubly reflected fields
- o Singly diffracted fields
- o Reflected-diffracted fields
- o Diffracted-reflected fields

Double diffraction is not computed in the NEC-BSC code. However, warnings are given in the printed output data, giving the angles at which double diffraction would occur, and identifying the mechanism which produces it.

The limited number of basic shapes (two) which the code makes available to geometrically describe a scattering structure somewhat restricts the ability of a user to faithfully represent a vehicle structure. The addition of a cone model and either a hemisphere or ellipsoid model would add appreciably to its applicability to actual flight vehicles. Perhaps a more serious deficiency is the fact that interaction (reflection and diffraction) between cylinders and flat plates (the two basic shapes) is not included in the computation. Blocking, or shadowing of the rays by these bodies is included, however. Interactions between two cylinders is computed, but only for a special case: that in which the axes of the cylinders are parallel, and only for the plane perpendicular to the cylinder axes.

The NEC-BSC code offers a great deal of flexibility to the user. Some of the options are:

1. It allows computation of either near fields or far fields.

2. Backscatter, bistatic scatter or antenna patterns may be computed.

3. Either great-circle cuts or conical cuts may be made.

4. The pattern coordinate system may be oriented in any desired way to the reference system.

5. Either electric or magnetic source types may be used.

6. The source current distribution may be selected from the basic options offered or may be input from the user's tabulated data.

7. Field values may be computed either as a function of angle or as a function of frequency.

The insight which the NEC-BSC code provides regarding the scattering mechanisms which operate in a particular problem is considered to be a very useful feature. This insight is provided by two methods:

1. The fact that the model of the scattering body is made up of discrete geometric elements enables the user to vary the parameters of a particular element, or perhaps to eliminate that element, to determine the nature and magnitude of the effect of that particular element on the overall pattern.

2. A selectable feature of the code permits the contributions of the individual scattering mechanisms (reflections and diffractions) to be printed out separately.

Thus, the antenna design engineer is assisted in anylyzing the scattering process.

In summary, the NEC-BSC code provides a very useful capability to rapidly compute antenna patterns which result from the use of various antenna types in complex scattering situations, but must be used with care to assure that the output data are valid. Caution is recommended in two areas:

1. Formation of the model should be performed in such a way as to achieve the best electrical approximation to the actual structure. The model which best describes the total physical structure may not be the best model.

2. The presence or absence of various scattering mechanisms in various geometric situations should be considered when interpreting the output data.

4.2 ESP3

The ESP3 code is based on use of the method of moments. In using this method, the scattering surfaces are divided into small areas, or "patches". Thus, the computer code is often referred to as a "patch code". The scattering structure is assumed to be illuminated by a specified incident wave or excited by an applied voltage in the antenna structure. An unknown value of current flows in each of the patch areas as a result of the incident wave or applied voltage. The direction and complex value of this current is determined by the direction, amplitude and phase of the incident field (scattering problem) or the location and value of the impressed voltage (antenna problem) and by compliance with the required boundary conditions. When the total field at a specified point is set equal to the sum of the contributions of the many (unknown) patch currents, an equation in many unknown quantities is obtained. If a second point is specified, a second equation is obtained. When the number of equations is equal to the number of unknowns, the resulting matrix may be inverted and the values of the unknown currents may be determined, as well as the value of the distant (or near) field which results from these currents.

The ESP3 code may be used for either antenna pattern computation or for computing the scattered fields which result from a body being illuminated by an incident wave. The scattering body (and the antenna structure, for the antenna problem) must be expressed by the user in terms of multi-sided flat plates and straight wire segments. The flat plates are divided by the code into the patch elements described above, and the currents which flow in these patches are expressed (as dictated by the user) as either surface current density modes or as filamentary currents. Currents in the wire segments are expressed, of course, as filamentary currents.

The user defines the structure by specifying the positions of the corners of the plates being used and the positions of the ends of the wire segments. Locations of load impedances and generators in the structure are also specified by the user. Plates and wires may be joined in any variety of ways to approximate the actual structure.

The ESP3 code treats the entire body as a single unit, rather than as a collection of separate scatterers, as with the NEC-BSC code. This treatment results in an advantage and a disadvantage. The advantage is that the computation does not depend on consideration of various scattering mechanisms associated with separate scattering elements (some of which may not be possible to compute). The disadvantage is that the insight gained by viewing the contributions of the individual scattering elements is lost. The net gain is a more rigorous treatment of the scattering problem.

As compared with the NEC-BSC code, the number of computations required when using the ESP3 code is enormous, and the computer run time reflects that fact. It is typically forty to sixty times as long as that required by NEC-BSC for the same problem. A larger working memory is also required. These characteristics are largely dependent on the electrical size of the model being used, the patch size selected and the choice of whether the patch current density mode or the filamentary current mode is used. In any case, the model should not exceed more than about three wavelengths across in size.

The ESP3 code should be most useful in two applications:

(1) Computation of antenna patterns or scattering properties of electrically-small antennas and/or scatterers.

(2) Computation of current distributions on antenna elements for inclusion in the input data of the NEC-BSC code.

Detailed information regarding the ESP3 code may be found in the User's Manual for that code.

5.0 SUPPLEMENTARY INPUT DATA PROGRAMS FOR NEC-BSC AND ESP3

Two additional codes, INSCAT and INDAT4 have been written by Applied Research to provide a more convenient means for entering input information required by the two OSU codes. When these codes are used, the required input information is requested from the user by questions presented on the monitor screen. These questions are answered, one at a time, from the keyboard. When all questions have been answered, the body of data is stored in a data file in the proper sequence and format, ready to be accessed by the main program. The use of these codes is optional.

The data files may also be prepared directly by the user by entering the required data in the input data file. The disadvantage of using this method is that the user must take care to place all data entries in their proper positions and in the proper format in the data file, and must not forget any required entry. No cues or directions are provided to the user by either OSU program (except by reference to the user's manual) in the input process.

Two command files have also been prepared for each of the OSU codes. For the NEC-BSC code, the user may initiate program execution by typing the command @SCAT1. This command calls up the SCAT1 command file which performs the following functions:

(1) It automatically calls the data input program INSCAT which requests the input information from the user.

(2) It assigns input and output files.

(3) It calls the NEC-BSC executable program SCAT, which runs and computes all required output data.

(4) It deassigns input and output files.

The user may choose to run the computational code SCAT without using the interactive input program. In this case, the initiating command is @SCAT2. It is assumed that the input data file has already been prepared. The SCAT2 command file performs the following functions:

(1) It assigns input and output files.

(2) It calls executable code SCAT, which runs and computes all required output data.

(3) It deassigns input and output files.

For the ESP3 code, two command files, PATCH1 and PATCH2, are also prepared. They are initiated by the commands @PATCH1 and @PATCH2, and they are used in the same manner as the commands @SCAT1 and @SCAT2 are used for the NEC-BSC code.

6.0 APPLICATION OF THE CODES TO LAUNCH VEHICLES AND SPACECRAFT

The NEC-BSC and ESP3 codes may be used in at least three ways in the analysis of antenna performance on launch vehicles and spacecraft:

(1) The nature and magnitude of the scattering effects of various structural elements may be evaluated individually or collectively.

(2) That portion of a scale model actually needed for antenna pattern range measurement may be determined analytically.

(3) Complete antenna radiation patterns for antenna/vehicle configurations may be computed, subject to the limitations of the code being used.

The first use mentioned may be highly beneficial when decisions regarding antenna type and location are being made. Effects on the composite antenna pattern by one or more structural elements will be determined in general by the primary pattern and polarization of the antenna being considered for use and by its location and orientation on the vehicle body. Evaluation of these effects by use of a computer should provide appreciable savings by reducing the time and cost involved in model preparation and pattern range measurement.

The second use mentioned above will enable the user to determine just how much of a vehicle scale model is really needed to obtain valid pattern data. In some cases, particularly those cases in which a very large vehicle is being scaled and a high frequency is being used, a large part of the model may not contribute appreciably to the pattern. If the entire body of such a vehicle is simulated by a model which has been scaled by a factor which enables it to be physically accommodated on the range, fabrication of scale-model antennas may be made difficult or impossible. However, if it has been determined that only a known fraction of the vehicle body contributes substantially to the pattern, then only that part of the body may be modeled, so that the scale factor does not need to be as great as would otherwise be required. Validation should be performed by comparison of computed patterns and measured patterns.

It is stressed that the computer codes produce their greatest benefit and least risk when used in conjunction with experimental measurements. They should not be thought of as stand-alone methods for the solution of antenna design problems.

6.1 Candidate Problem: Use of Radar Antenna on Shuttle SRB.

It has been suggested that one of the selected codes be used to analyze the effects of the Space Shuttle orbiter, the external tank and the solid-rocket boosters (SRB) on the radiation pattern produced by a radar transponder antenna located in a specified region on the surface of an SRB as shown in Figure 1. This problem has been examined and the analytical capability of the two codes has been evaluated for the recommended case.

6.1.1 Feasibility of using the ESP3 code.

Use of the ESP3 code is not feasible for scattering bodies of more than about three wavelengths in size. The shuttle configuration has dimensions of hundreds of wavelengths. Therefore, this code is clearly not suitable for use in solution of this problem.

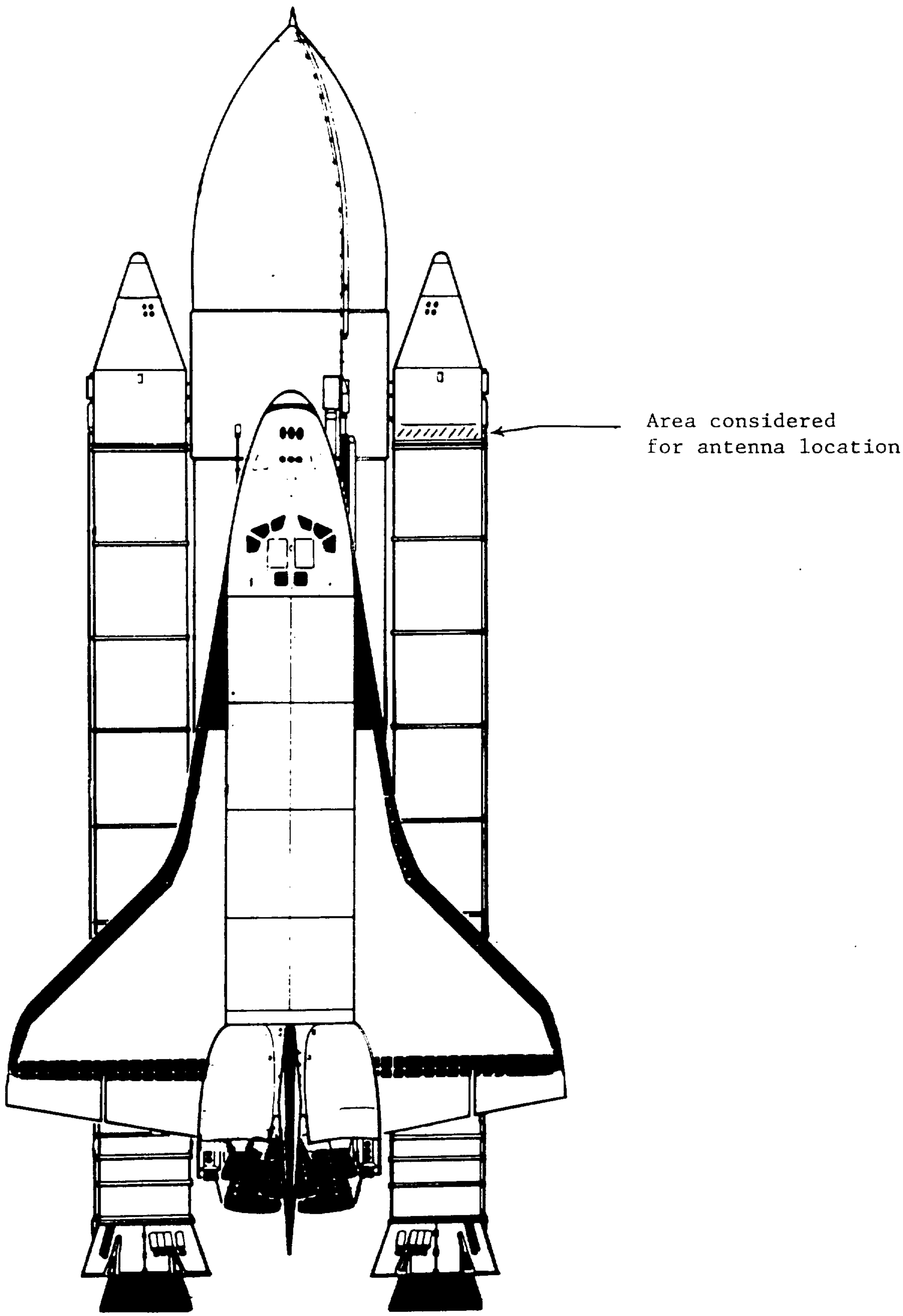


Figure 1. Space Shuttle.

6.1.2 Feasibility of using the NEC-BSC code.

The NEC-BSC code, being based on the Geometrical Theory of diffraction, is best suited to handling scattering computations which involve structures of the size being considered. It also has the advantage that one of its basic geometric models is the cylinder, so that the SRBs and the external tank, both having a cylindrical cross-sectional shape, may be modeled directly, but with some limitations. The orbiter may be modeled by use of flat plates and cylinders, but may require a large number of these elements for satisfactory fidelity.

Before proceeding with a discussion of the analytical method, the elements of this problem which impose limitations on the type and quality of computed pattern data will be identified.

(1) The region of the SRB being considered for locating the transponder antenna contains surface irregularities in the form of circumferential rings. The ability to assess the affects of these rings has not been determined.

(2) That portion of the external tank which lies alongside the antenna location region of the SRB has an external surface characterized by a corrugated shape. The electrical size of the corrugation segments is large at the radar frequency, so that the surface cannot be modeled as that of a smooth cylinder, nor can it be represented adequately as a surface impedance.

(3) The shapes of the forward and aft ends of the SRB and of the external tank cannot be precisely modeled. This deficiency may not be very important.

(4) Interaction (excluding shadowing) between either of the SRB bodies and the external tank and between the two SRB bodies can be computed only in the roll plane.

(5) If the orbiter body is modeled as a combination of flat plates and elliptic cylinders, only first-order scatter mechanisms will be computed for that body.

(6) Effects of surface coatings have not been evaluated.

In view of the above considerations, computation of the radiation pattern of an SRB antenna, taking into account the effects of the entire structural configuration, may seem a very questionable task. Indeed, the complexity of the configuration, together with certain limitations of the NEC-BSC code, dictate that the task be conducted in a way in which these factors are considered in the formulation of the problem, so that computation of invalid data can be minimized.

It appears that maximum benefit can be derived from use of the code by first evaluating the effects produced by specific portions of the total structure, thus gaining an understanding of the magnitude and nature of each contribution to the composite pattern. An advantage of this approach is that the validity of the computed composite pattern for the total structure can be more accurately assessed. Also, those portions of the structure that are shown to produce negligible effects can be eliminated from the total model. Computed patterns for small sections of the model may be validated by performing experimental pattern measurements for those sections.

6.1.2.1 Modeling of the Proposed Antenna

The first step that was taken in assessing the feasibility of using the NEC-BSC code in solving the SRB antenna problem was to consider the possibility of modeling an antenna which is being considered for use in this application. The candidate antenna is a crossed cavity-backed slot antenna. Its operating frequency is in the C band. Unfortunately, the code does not include the capability to model any source that is located on a curved surface, and the candidate antenna is of that type. The problem posed by this limitation reaches far beyond the scope of the SRB radar antenna problem, of course, because a large number (if not most) launch vehicle and spacecraft antennas are mounted on curved surfaces. Thus, it is very important that some method be devised to model such antennas in a way that the code will accept and which will produce valid data.

In considering a surface-mounted cavity-backed slot antenna, it was realized that a half-loop antenna of suitable size, mounted on a flat ground plane and having a uniform current distribution, is the electrical equivalent of the slot as far as pattern and polarization are concerned. This realization led to the consideration of the possibility of using a set of theoretical current segments, arranged above the surface in such a way as to produce fields which are approximately those of a half loop. In order to minimize the required number of segments, a rectangular "half-loop" configuration was selected, requiring only three segments, as shown in Figure 2a. However, even this configuration violates a requirement of any GTD code: that a space of at least 1/4 wavelength exist between any two elements of the system. Two of the elements in Figure 2a are touching the ground surface. This deficiency was removed by raising these two elements to the positions shown in Figure 2b. It must be realized that this model does not represent an actual antenna configuration of this shape. Such an electrical current arrangement would not be achievable in practice; it would violate the basic electrical laws. However, it is quite acceptable as a theoretical source model. The model is further improved by making the end elements shorter and increasing their current amplitude accordingly. The "SM:" source mode was used in this modeling process. It permits assignment of any arbitrary value of current and any orientation to individual current segments, and these currents do not interact with each other. Both magnitude and phase of the current in each segment is specified independently. The capability to independently specify all of

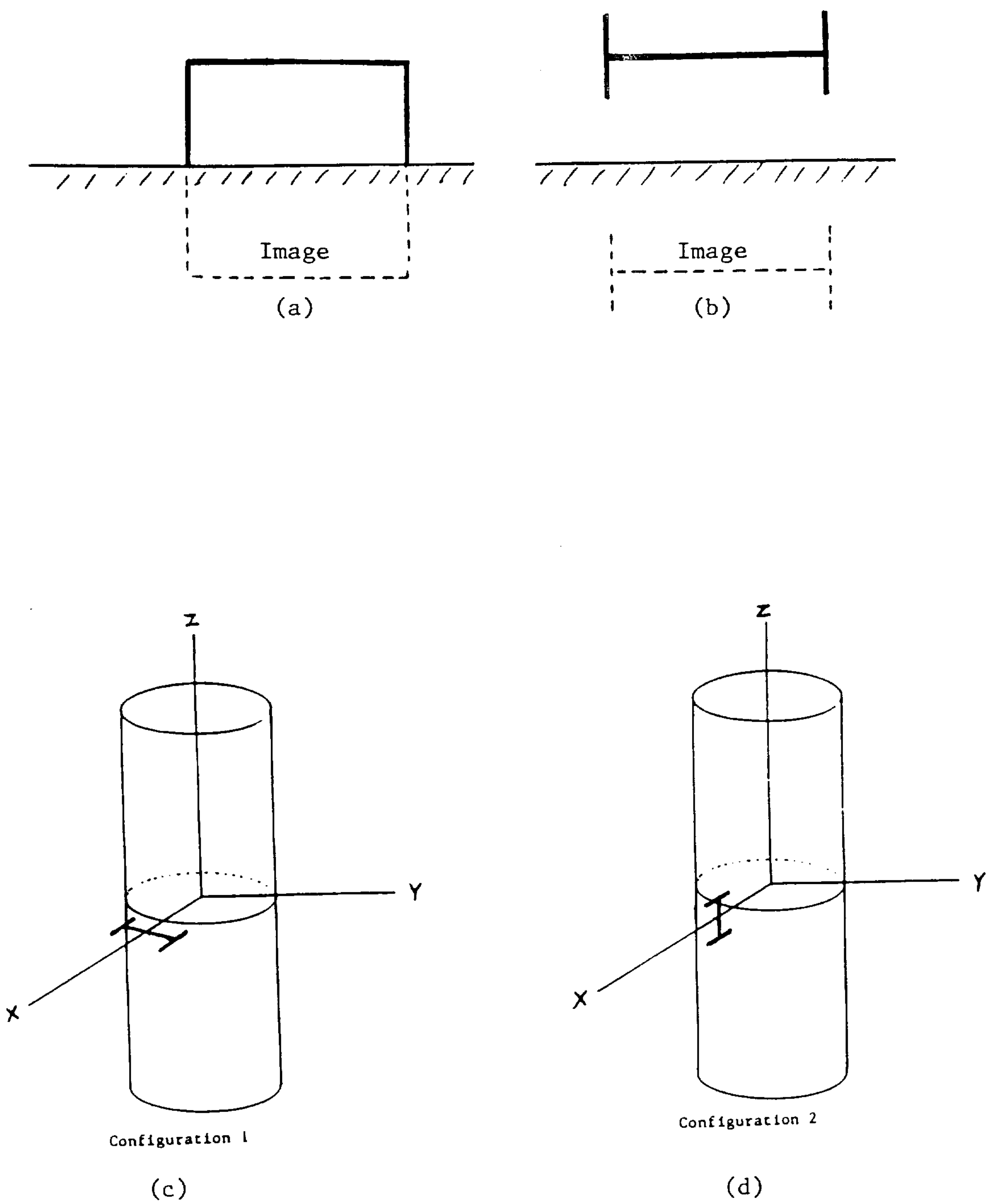


Figure 2. Antenna model.

these variables provides a very powerful means for producing a theoretical model which closely approximates the performance of the actual antenna.

The three-element configuration described above may be used to simulate a single slot. If an identical configuration is used and rotated 90 degrees, the second slot of the crossed-slot antenna is simulated. If the first configuration is so arranged that all three of its elements lie in the plane normal to the axis of the cylinder over which it is located, and the second one is arranged so that its elements lie in the plane of the cylinder axis, we have what will henceforth be referred to as Configuration 1 and Configuration 2, respectively.

Two sets of antenna patterns were computed. The first set was computed by use of the current-segment model in conjunction with a 24-inch long by 24-inch diameter circular cylinder. These patterns were computed in an attempt to duplicate the measured patterns provided by the manufacturer of the antenna that is being considered. The manufacturer's patterns are shown in Figure 3. The patterns seem to indicate that the two slots were driven with equal power levels and 90 phasing. The second set of patterns were computed by use of the same antenna configurations as used in the first set, but with a 12-foot diameter cylinder, simulating the SRB body. Patterns were computed for the pitch plane and for the roll plane for each of the two antenna configurations.

Computed patterns for the 24 x 24 inch cylinder will be discussed first. Only the dominant polarization component will be considered in each case, the other component being essentially zero for the principal planes. The roll-plane cut for configuration 1 is shown in Figure 4. The strong creeping-wave propagation (diffraction) around the surface of the small-diameter cylinder is evident. The amplitude of the far-field signal is down only about 12 dB. from the peak value at 120 degrees around the cylinder from the antenna. This pattern may be compared with the pattern entitled "ROLL PLANE, LINEAR VERTICALLY" from the antenna manufacturer's patterns shown in Figure 3, or with the outer envelope of the pattern entitled "ROLL PLANE, ROTATING LINEAR" The degree of agreement cannot be determined with certainty because no dB. scale is shown on the manufacturer's pattern charts.

The pitch plane pattern for configuration 1 on the 24 x 24 inch cylinder is shown in Figure 5. The dominant polarization component in this case is produced by the current element that is parallel to the cylinder surface. Therefore, its radiated signal will fall to almost zero in the directions of the cylinder axis, just as that of a longitudinal slot antenna would do. It does not abruptly fall to zero in those directions because of the finite length of the cylinder (12 inches in each direction), as seen in Figure 5 and in the inner envelope of the pattern entitled "PITCH PLANE, ROTATING LINEAR" of Figure 3. Note that the pattern in

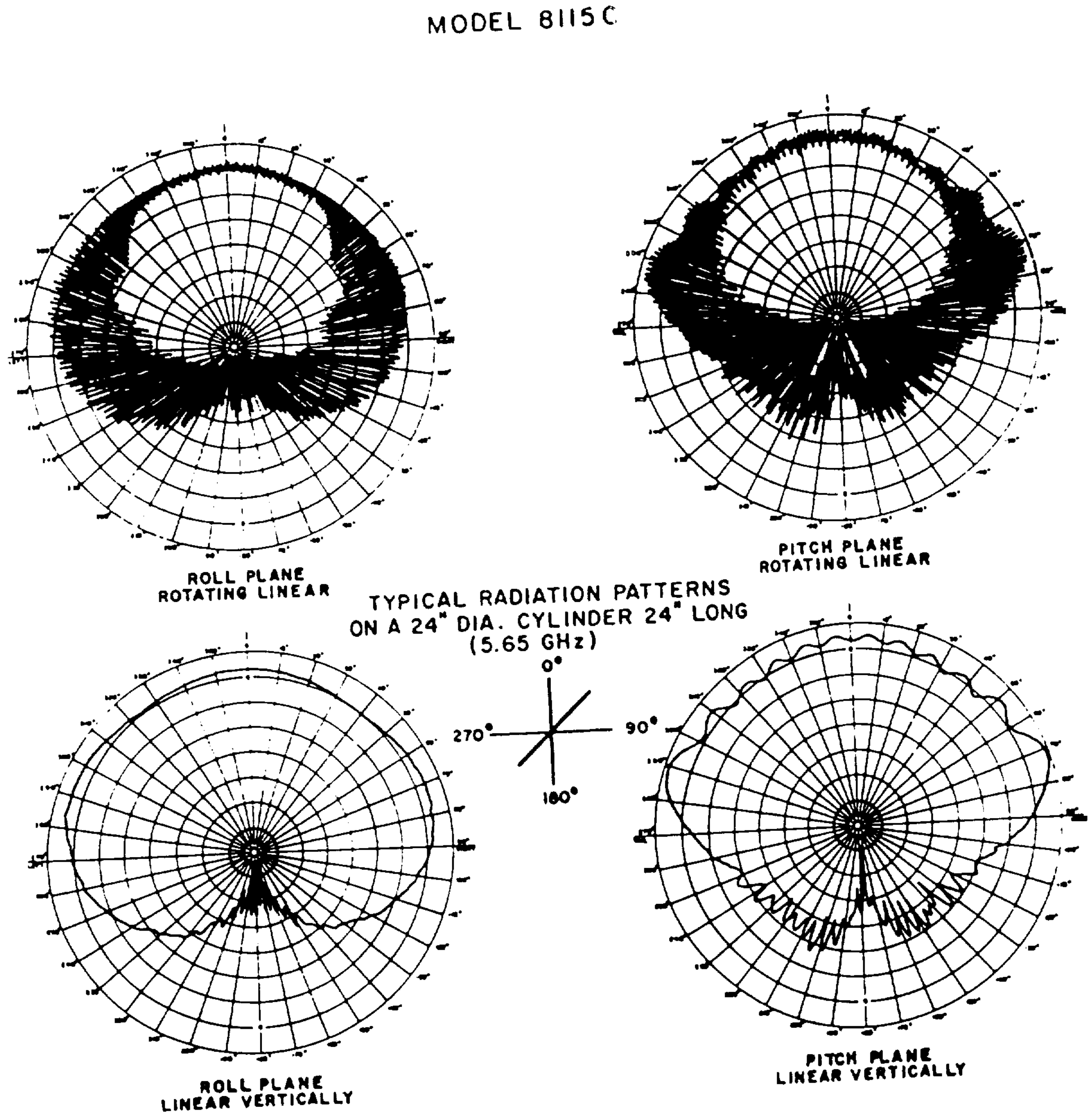


Figure 3. Measured patterns of crossed-slot antenna.

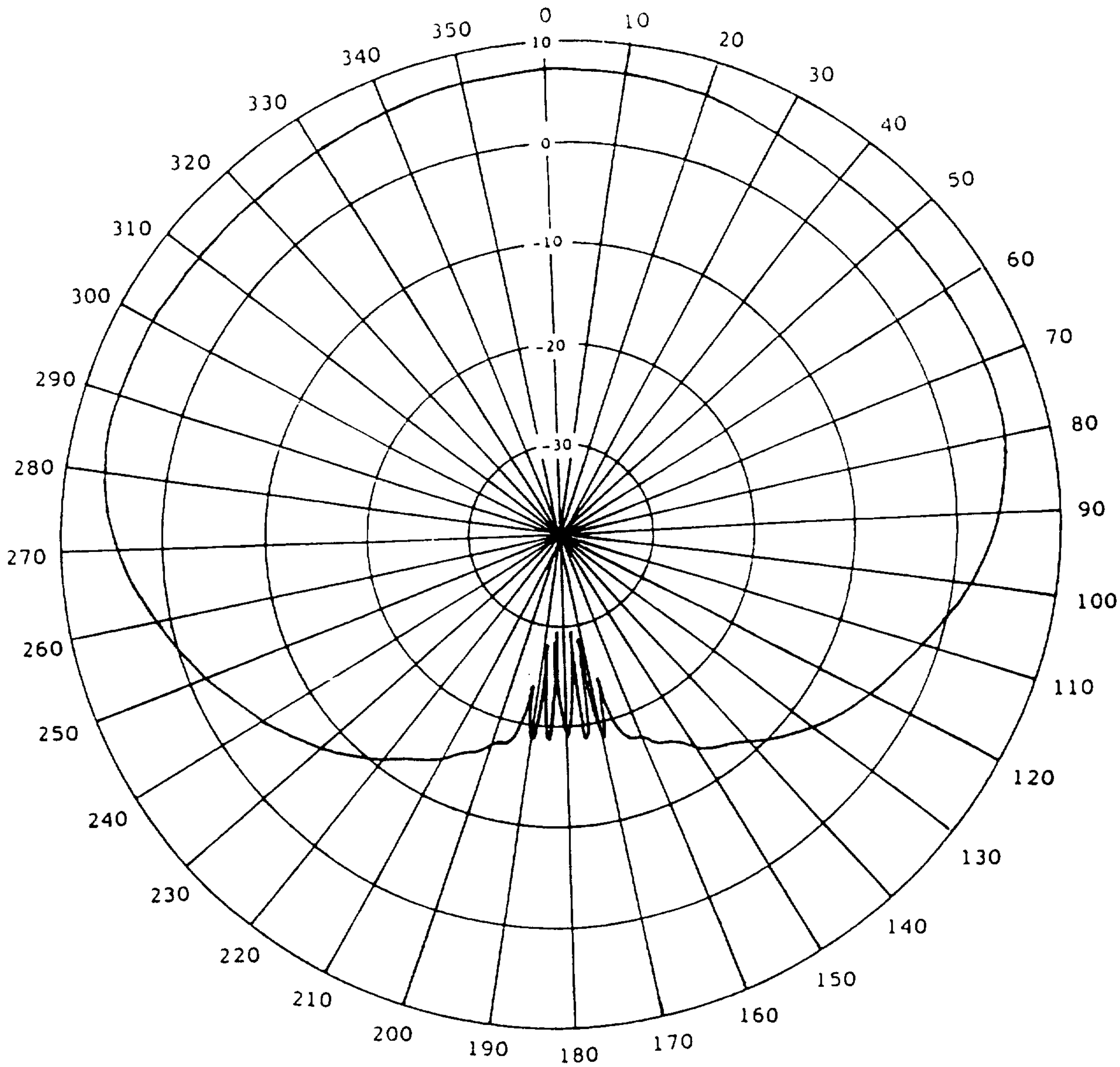


Figure 4. Pattern of antenna model, configuration 1, on 24" x 24" cylinder, roll plane.

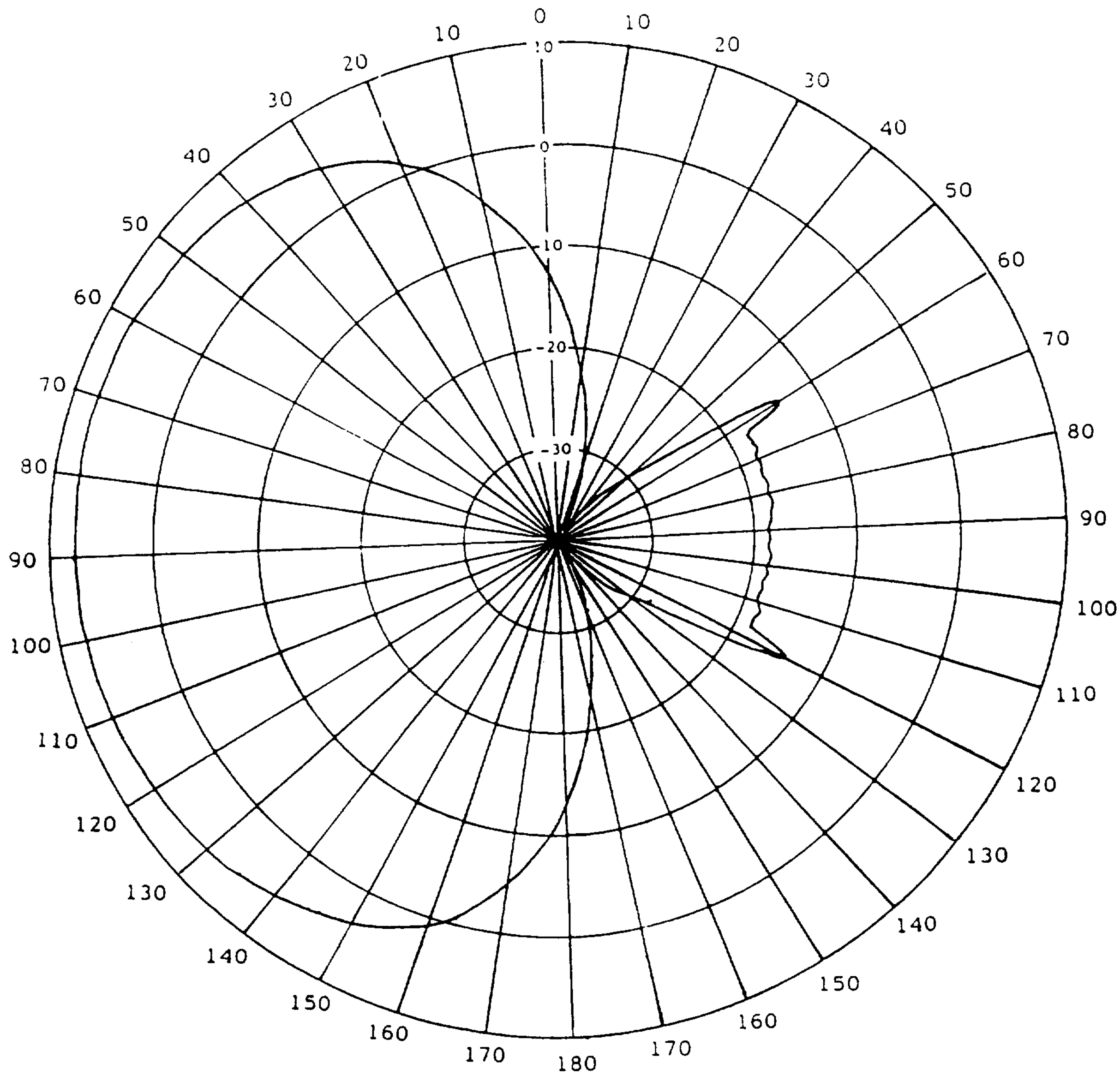


Figure 5. Pattern of antenna model, configuration 1, on 24" x 24" cylinder, pitch plane.

Figure 5 is rotated 90 degrees relative to that shown in Figure 3. The reason for the radiation in the interval between the angles of 60 degrees and 120 degrees is not clear. However, the level in this region is 23 dB. or more below the peak level, so is perhaps not significant.

The roll-plane pattern for configuration 2 on the 24 x 24 inch cylinder is shown in Figure 6. The dominant contribution is from the current element that is parallel to the cylinder surface, and rolls off fairly rapidly near the 90-degree and 270-degree angles, just as that of a circumferential slot antenna would do. It does not fall abruptly to zero at those angles because of the finite size and the curvature of the cylindrical surface. This pattern should be compared to the inner envelope of the pattern entitled "ROLL PLANE, ROTATING LINEAR" in Figure 3. Note that there is a single value of 9.6 dB. computed at the angle of 180 degrees. All adjacent values are below -30 dB. This is clearly a computational error. The reason for this error is not known.

The pitch-plane pattern for Configuration 2 on the 24 x 24 inch cylinder is shown in Figure 7. Using this configuration and pattern plane, all three current segments in the configuration contribute to the radiated signal to generate the dominant polarization component. The situation is analogous to that of the circumferential slot antenna, which would have an omnidirectional pattern in the half-plane if the length and diameter of the cylinder approached infinity. The pattern deviates from that shape because of diffraction at the ends of the cylinder. Comparing the pattern of Figure 7 with the pattern entitled "PITCH PLANE, LINEAR VERTICALLY" in Figure 3 (note the 90-degree rotation) or with the outer envelope of the pattern entitled "PITCH PLANE, ROTATING LINEAR", the patterns are seen to be very similar except in the region around 90 degrees in Figure 7 (180 degrees in Figure 3). The computed pattern of Figure 7 goes to an extremely high value at 90 degrees, while the measured pattern of Figure 3 falls almost to zero in that region (180 degrees). It may be noted that we are operating in the plane that contains the 9.6 dB. anomaly seen in Figure 6.

6.1.2.2 Application of Antenna Model to SRB

After computation of patterns in the principal planes for each of the two model antenna configurations on a 24 x 24 inch cylinder, the two configurations representing the two slots of the proposed antenna, and after comparing the computed patterns with measured patterns, the two model configurations were used in conjunction with a cylindrical body having the same diameter (12 feet) as the SRB. The length of the body was 20 feet. This length was chosen, not to represent the actual length of any part of the SRB, but to minimize the effects of diffraction at the cylinder ends. The flat ends of the model cylinder would not represent the actual shapes of the forward and aft ends of the SRB very satisfactorily. Again, patterns were computed in the

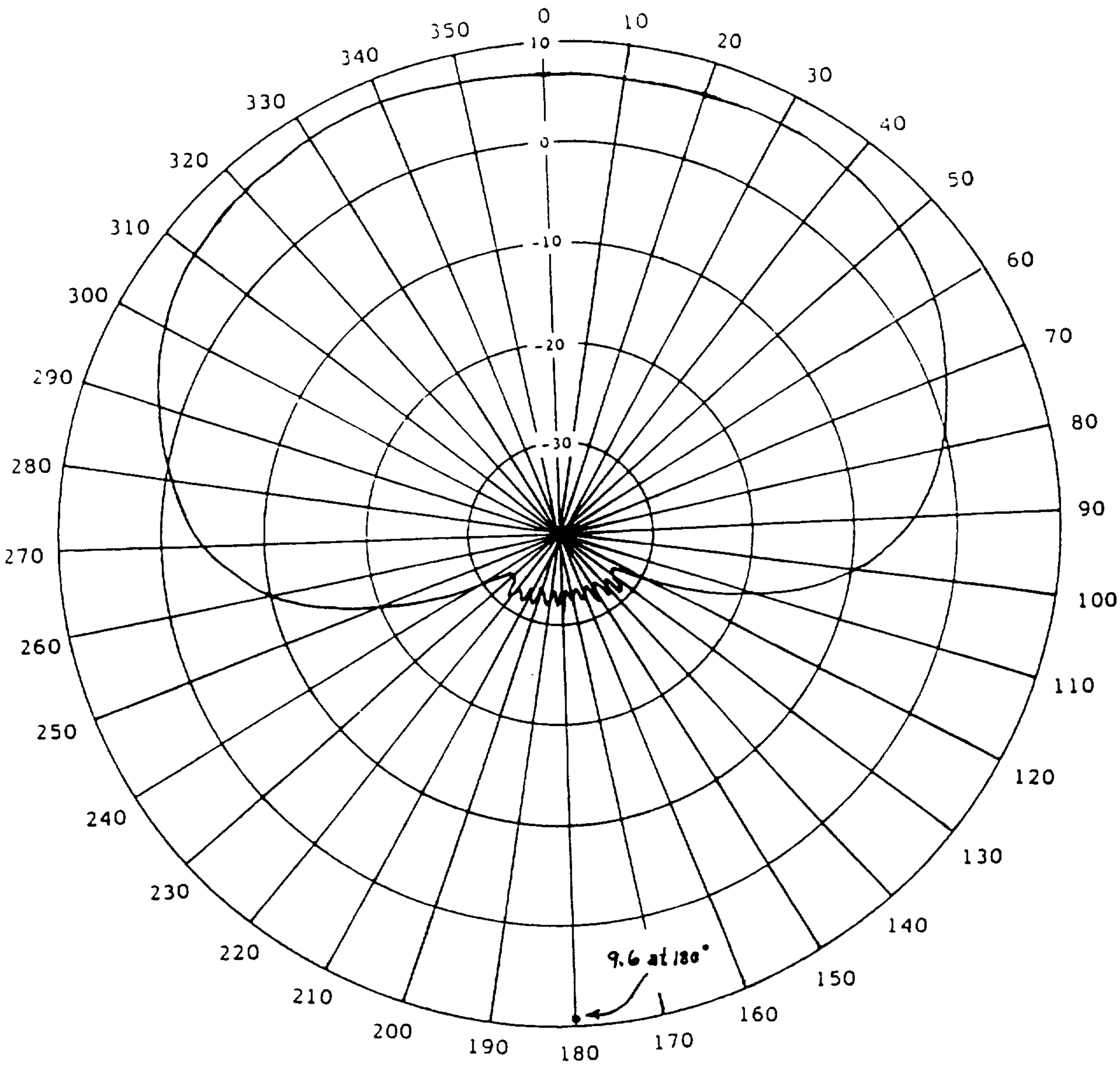


Figure 6. Pattern of antenna model, configuration 2, on 24" x 24" cylinder, roll plane.

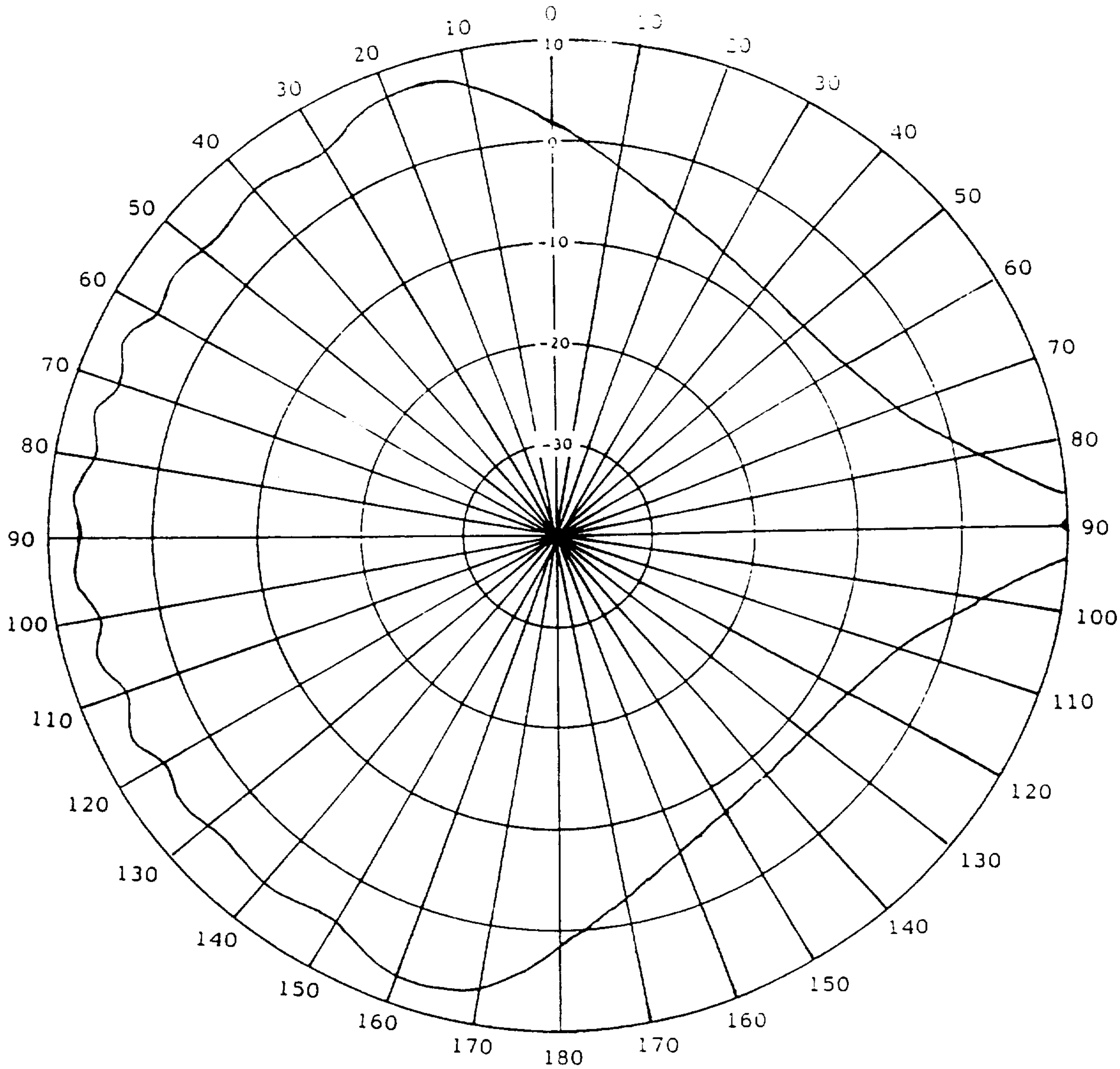


Figure 7. Pattern of antenna model, configuration 2, on 24" x 24" cylinder, pitch plane.

principal planes (roll and pitch) for each of the model antenna configurations. The computed patterns are shown in Figures 8 through 11.

The roll-plane pattern for Configuration 1 is shown in Figure 8. Comparison with the pattern shown in Figure 4 reveals the same basic shape, except that the radiation does not wrap around the larger cylinder to nearly the extent that it does in the case of the 24-inch diameter cylinder, as would be expected. The absence of the lobe structure around the 180-degree direction seen in Figure 4 is attributable to the lack of appreciable creeping-wave diffraction around either side of the cylinder in the 180-degree region. The waves attenuate to a negligible value after propagating around 1/4 the circumference of the 12-foot cylinder.

The pitch-plane pattern for Configuration 1 is shown in Figure 9. It is very similar to the pitch-plane pattern of Configuration 1 on the 24 x 24 inch cylinder, shown in Figure 5. One notable difference is the absence of radiation in the 60-degree to 120-degree range seen in Figure 5. This difference evidently results from the weaker illumination of the diffracting edges at the ends of the 20-foot long cylinder.

The roll-plane pattern for Configuration 2 is shown in Figure 10. It compares favorably with the corresponding pattern shown in Figure 6, except that an apparent computational anomaly appears in a 4-degree angular region around the 180-degree direction. The validity of the computed data in this region has not been determined. Otherwise, the pattern shape is that which would be expected from a circumferential slot in a cylinder such as this one.

The pitch-plane pattern for Configuration 2 is shown in Figure 11. It may be compared with the pattern shown in Figure 7 for the 24 x 24 inch cylinder. The left-hand sides of the two patterns are very similar, and are the patterns which one would expect from a circumferential slot. The strongly-illuminated ends of the small cylinder (they are close to the source) produce diffracted waves which interfere to produce a ripple in the pattern from 0 to 180 degrees. This ripple is not seen in the pattern of the large cylinder, where the ends are far from the antenna and thus are weakly illuminated. The right-hand side of the pattern is not clearly understood. The apparent anomaly in Figure 7 has been discussed in Paragraph 5.1.2.1. The split lobe appearing in the 90-degree region on the right-hand side of Figure 7 corresponds to the pair of lobes seen in Figure 11 at 38 degrees and 142 degrees. The difference between the two cases is the wide separation of the two lobes in the SRB case (long cylinder) as compared with narrow separation in the case of the 24-inch long cylinder.

An additional pattern (Figure 12) was computed to confirm the apparent relation between the lobe positions and the cylinder

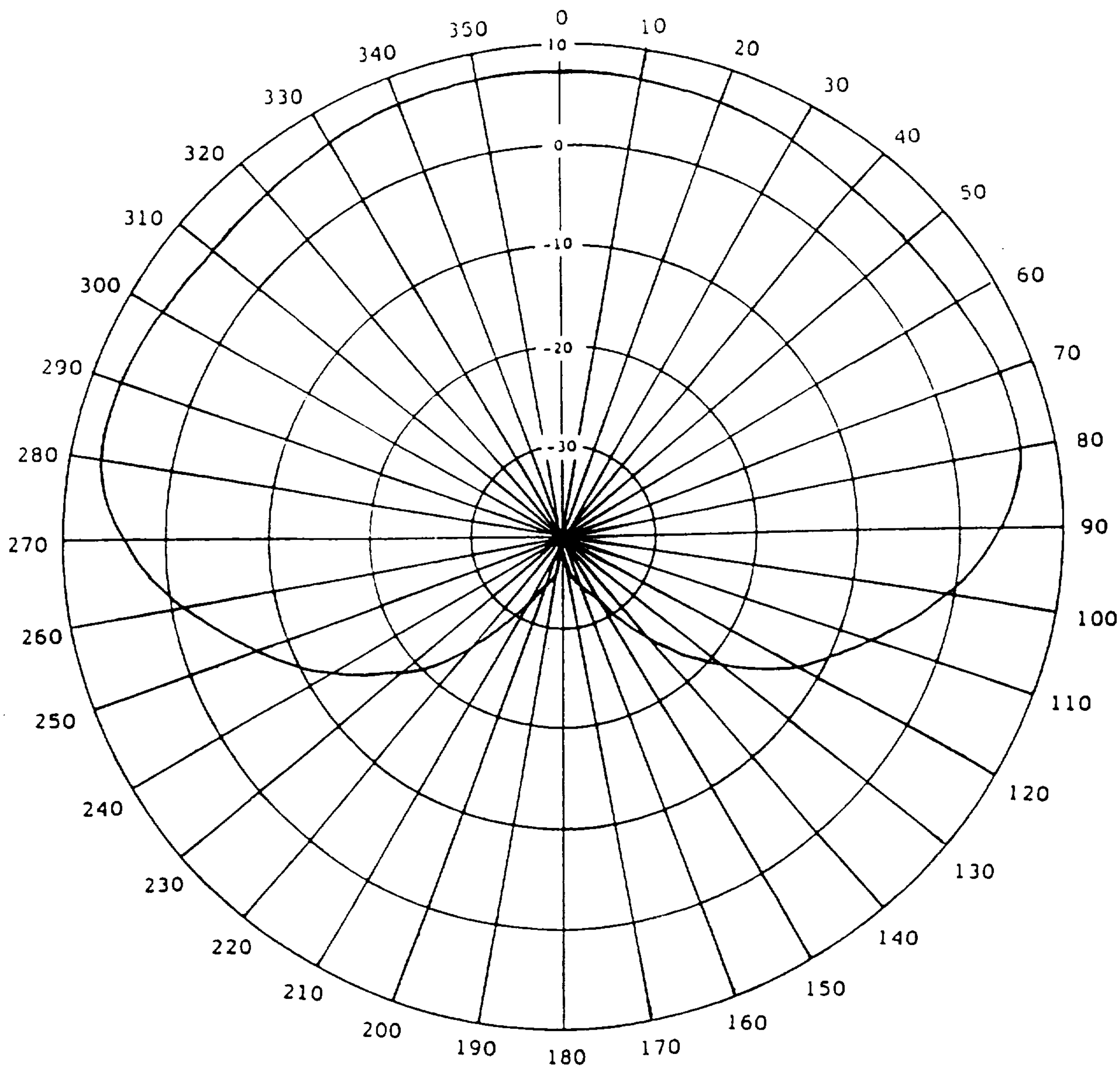


Figure 8. Pattern of antenna model, configuration 1, on 12-foot diameter cylinder, 20 feet long. Roll plane.

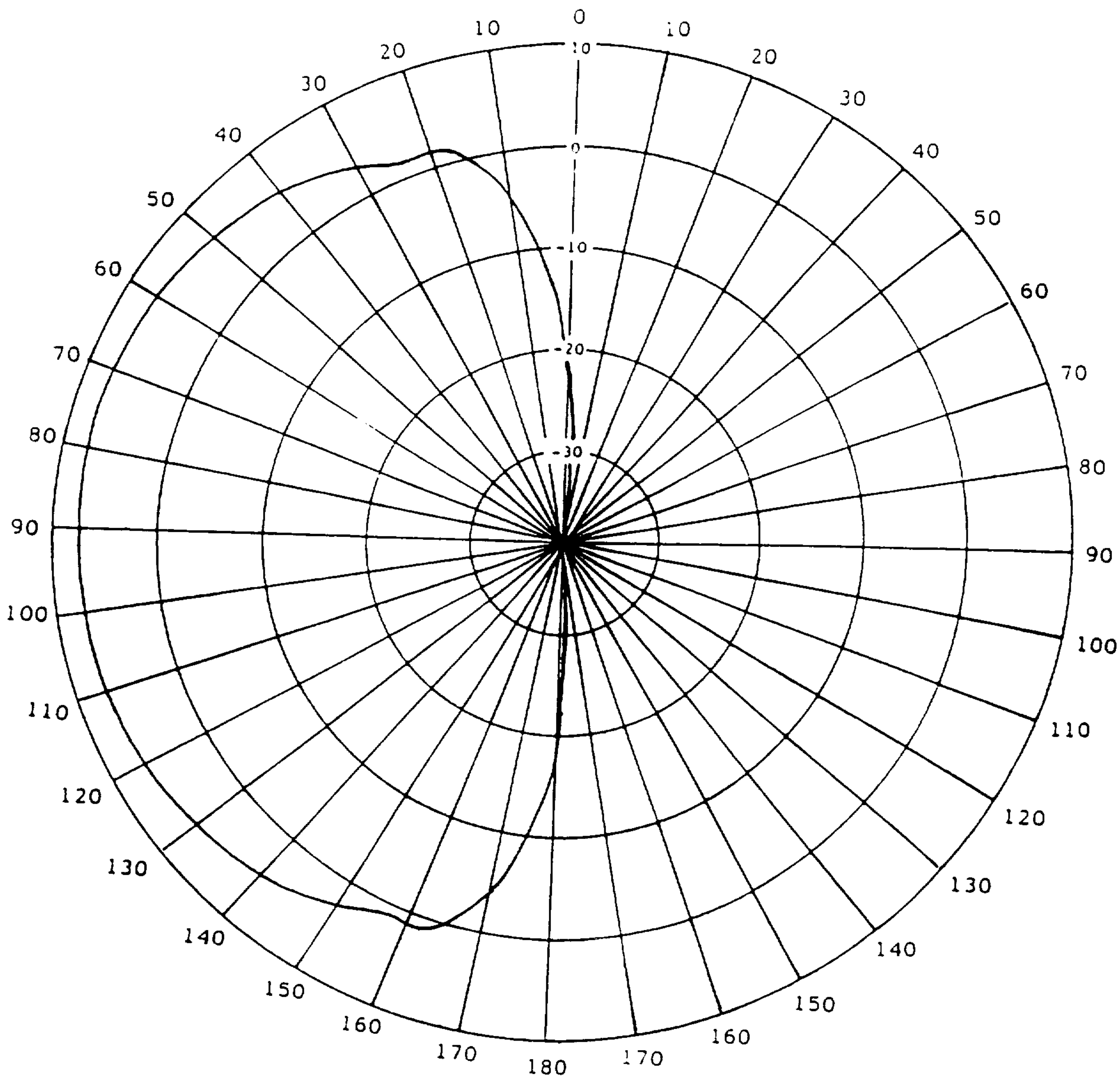


Figure 9. Pattern of antenna model, configuration 1, on 12-foot diameter cylinder, 20 feet long. Pitch plane.

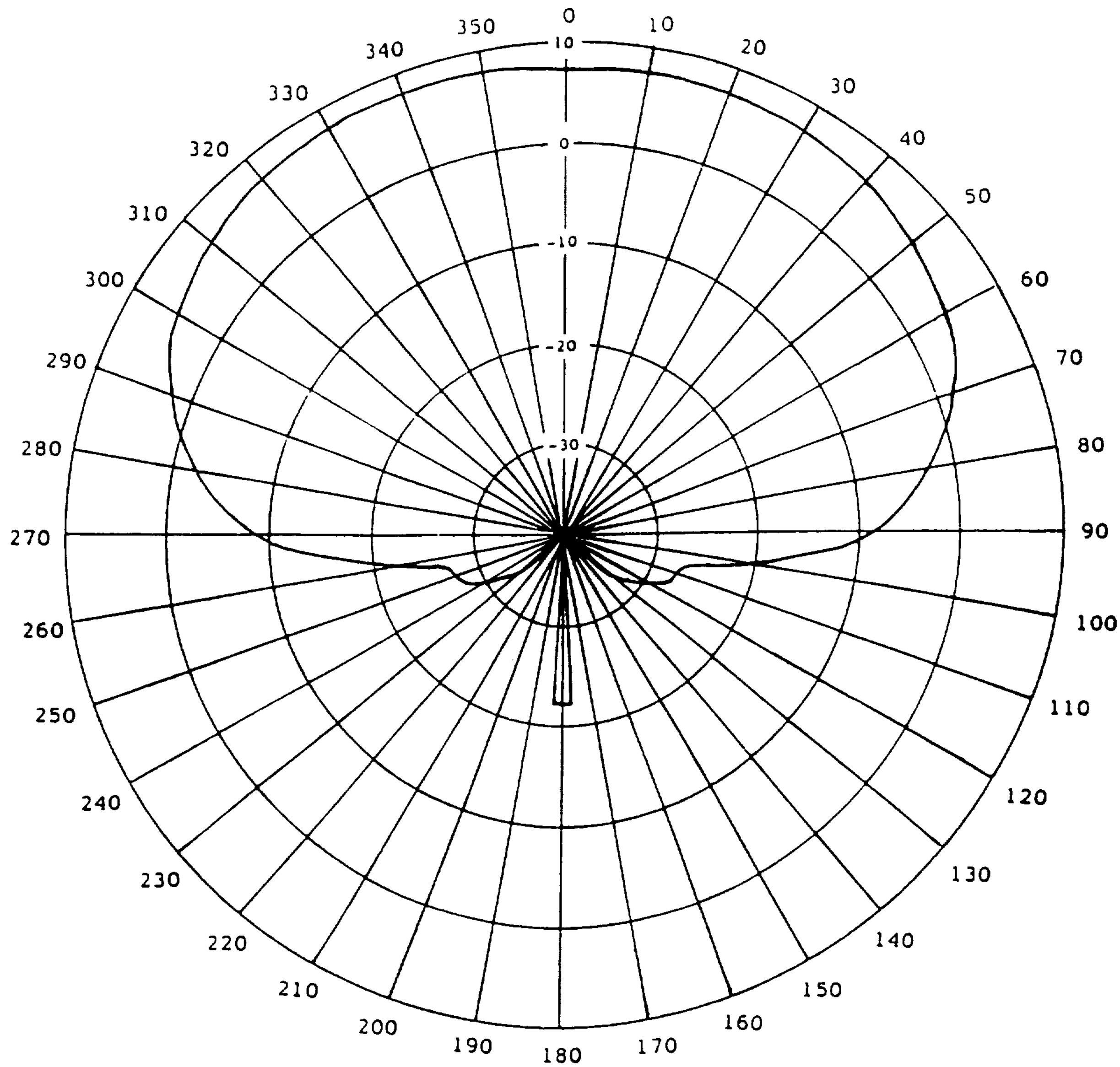


Figure 10. Pattern of antenna model, configuration 2, on 12-foot. diameter cylinder, 20 feet long. Roll plane.

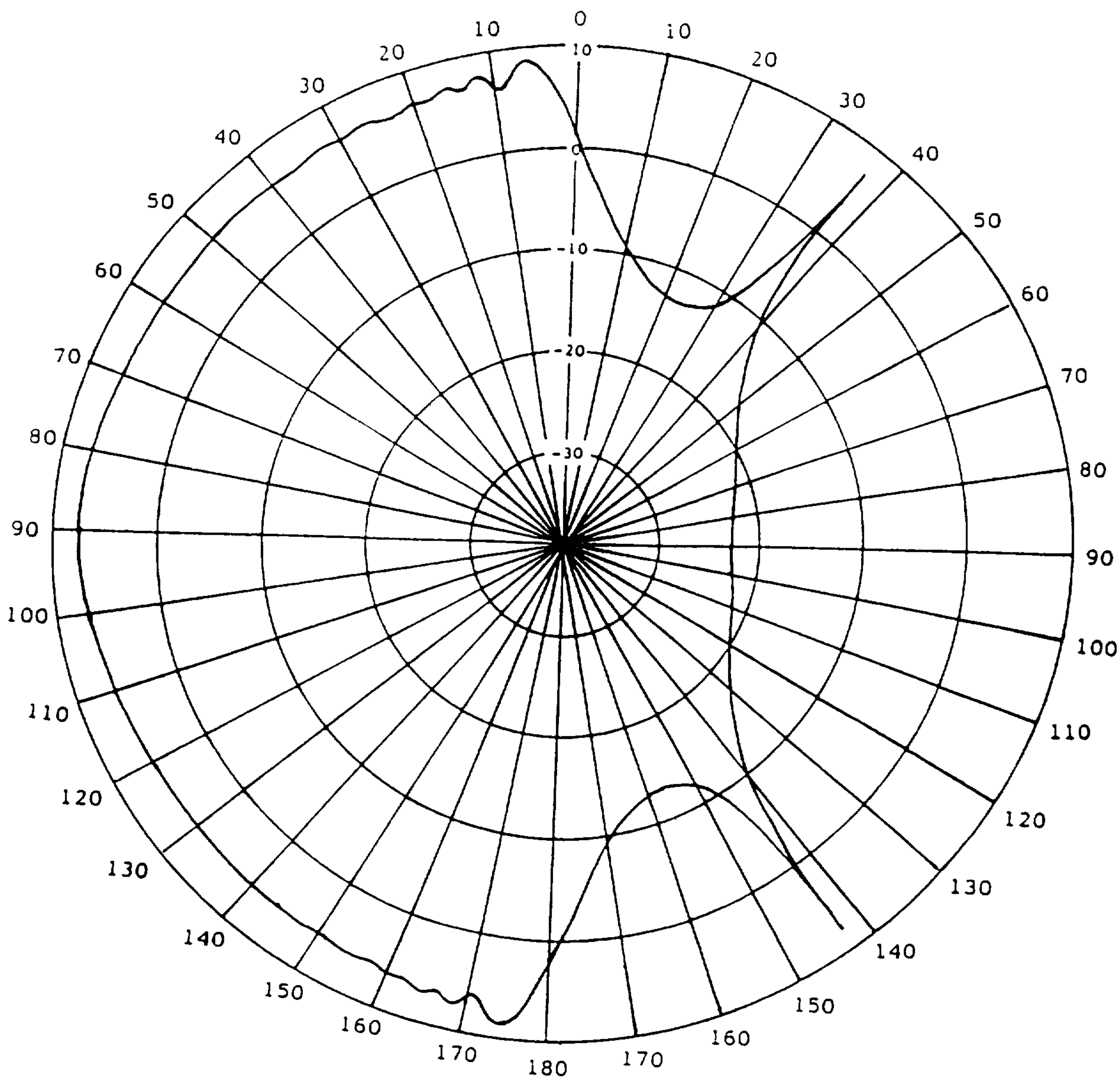


Figure 11. Pattern of antenna model, configuration 2, on 12-foot diameter cylinder, 20 feet long. Pitch plane.

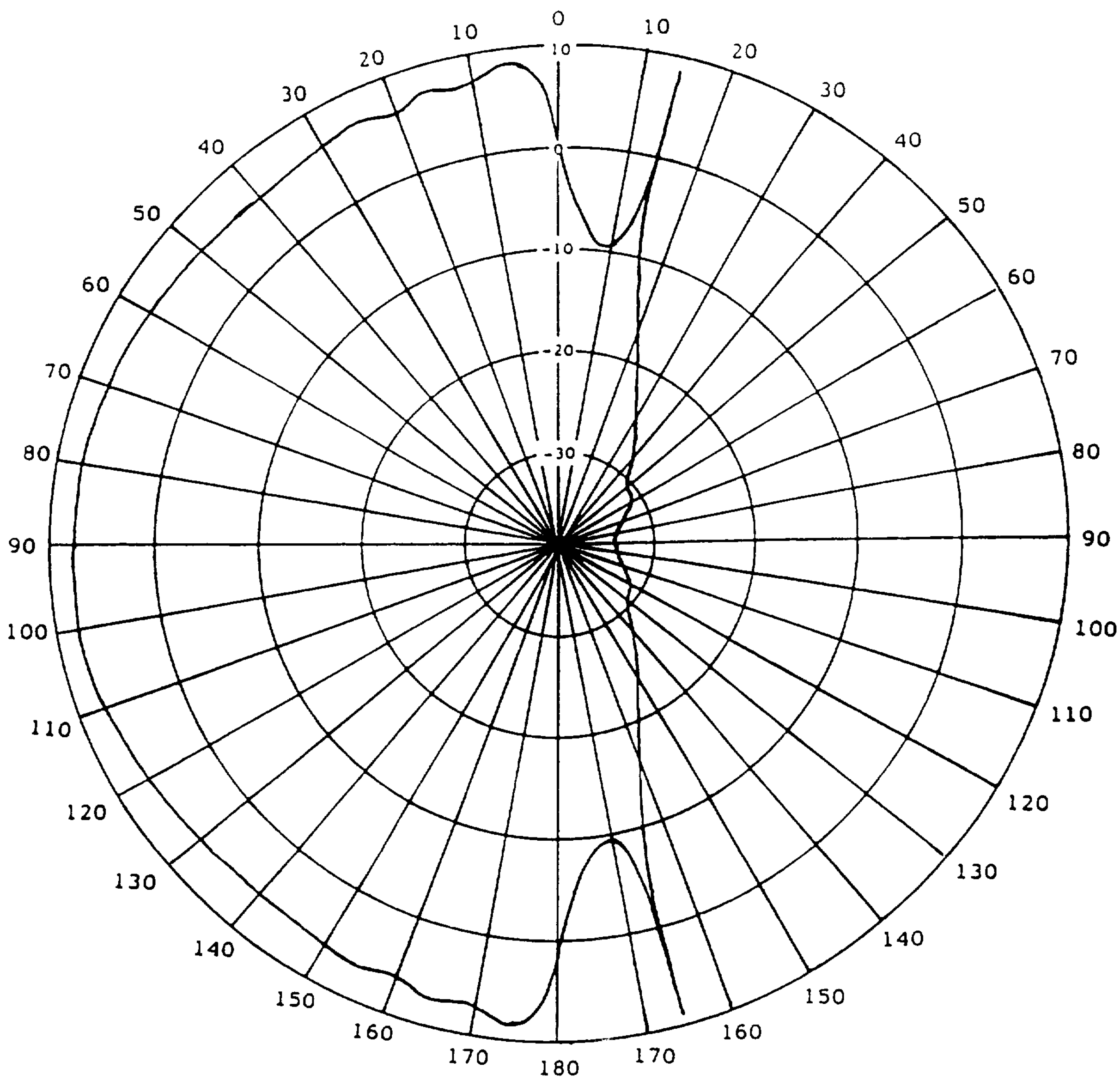


Figure 12. Pattern of antenna model, configuration 2, on 12-foot diameter cylinder, 50 feet long. Pitch plane.

length. The cylinder length in this case was increased from 20 feet to 50 feet. The diameter was unchanged. The two lobes in the right-hand portion of the pattern are seen to move closer to the axial directions, the same direction that they moved when the length was changed from 2 feet to 20 feet.

It may be concluded from a comparison of the patterns that these lobes are related to the diffracted radiation from the edges at the ends of the cylinder. The phase variation of the excitation along one of these edges is related to the distance between the edge and the source. Thus, it may be expected that the pattern of the diffracted radiation will be a function of the cylinder length. However, the phenomenon is not well understood, and requires additional study.

6.1.2.3 Consideration of multiple cylindrical bodies

Three of the four bodies which make up the Space Shuttle configuration are right-circular cylinders terminated in ends of various shapes. Although it is recognized that the external tank has a surface pattern in the antenna location region for which no modeling method is known, it was neverless considered instructive to examine the composite effects of two cylindrical bodies having the same diameters and relative positions as the SRB and the external tank.

6.1.2.3.1 Two-cylinder configuration using 24-inch diameters.

Before proceeding to the shuttle simulation, two patterns were computed for the case of the simulated antenna on a 24-inch diameter cylinder, with another 24-inch diameter cylinder located nearby. The axes of the cylinders are parallel. Each cylinder is 200 inches long. The antenna (configuration 1) is located midway between the ends of the cylinder above which it is mounted. The operating frequency is 5.65 gHz. The computed patterns reveal some of the characteristics of the NEC-BSC code.

The configuration chosen for the first pattern is shown in Figure 13. The second cylinder is located directly above the antenna, the cylinder axes being 36 inches apart (12 inches between the cylinders). The pattern is taken in the roll plane.

The single and multiple scattering effects produced by the two cylinders are very evident in the pattern of Figure 13. The value of relative gain rapidly changes at four points around the pattern, labeled A, B, C and D. The reason for these changes may be seen by inspection of Figure 14. The ray path OCE consists of a direct ray OC from the current element to the tangent point on cylinder 2, thence around the circumference, as a creeping wave, to a second tangent point from which it radiates toward E. The mechanism consists of a single diffraction, and is computed for the entire shadow region shown on the sketch.

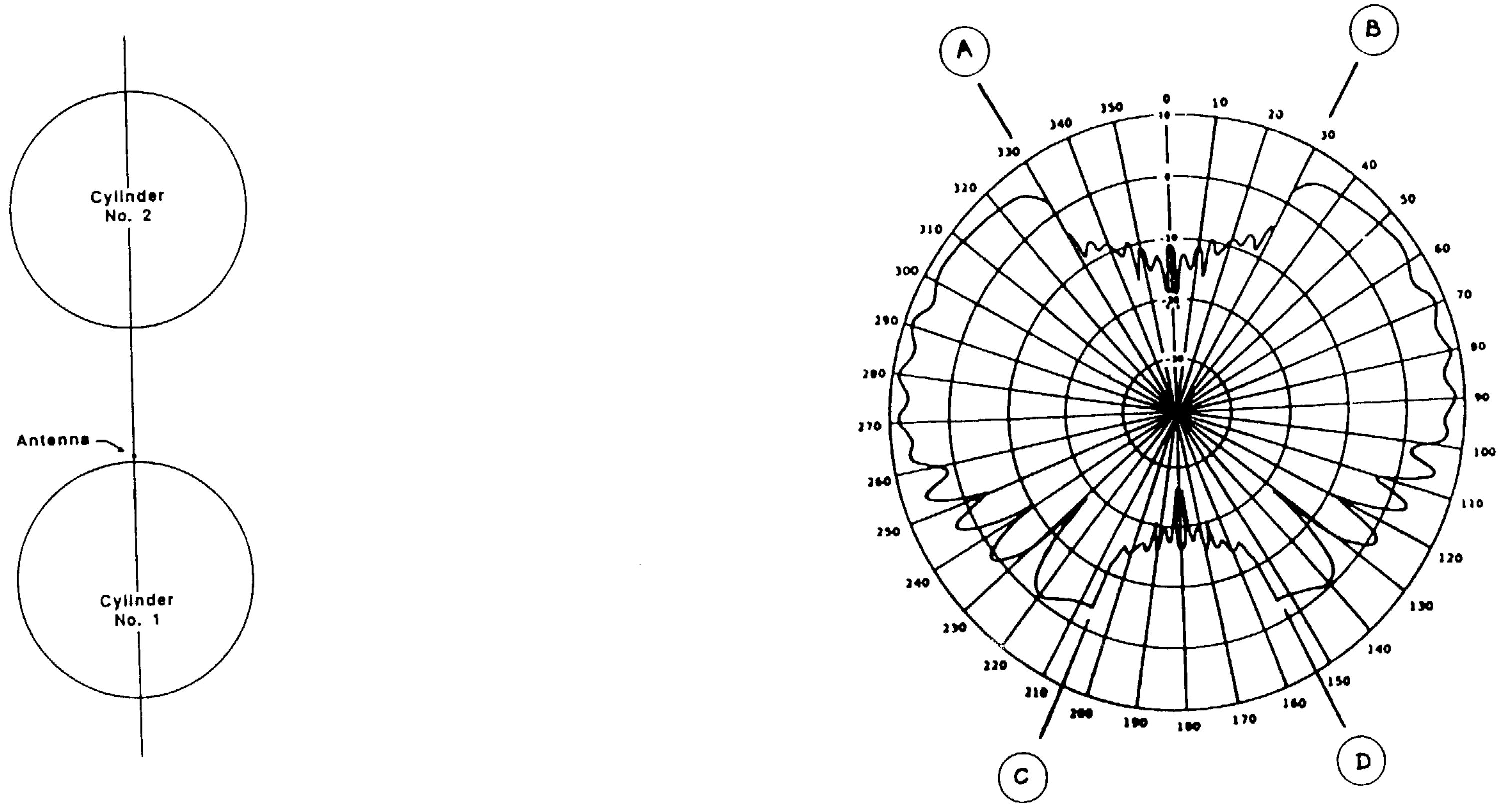


Figure 13. Pattern of antenna model, configuration 1, with 2-cylinder configuration. Cylinder diameters = 24 inches.

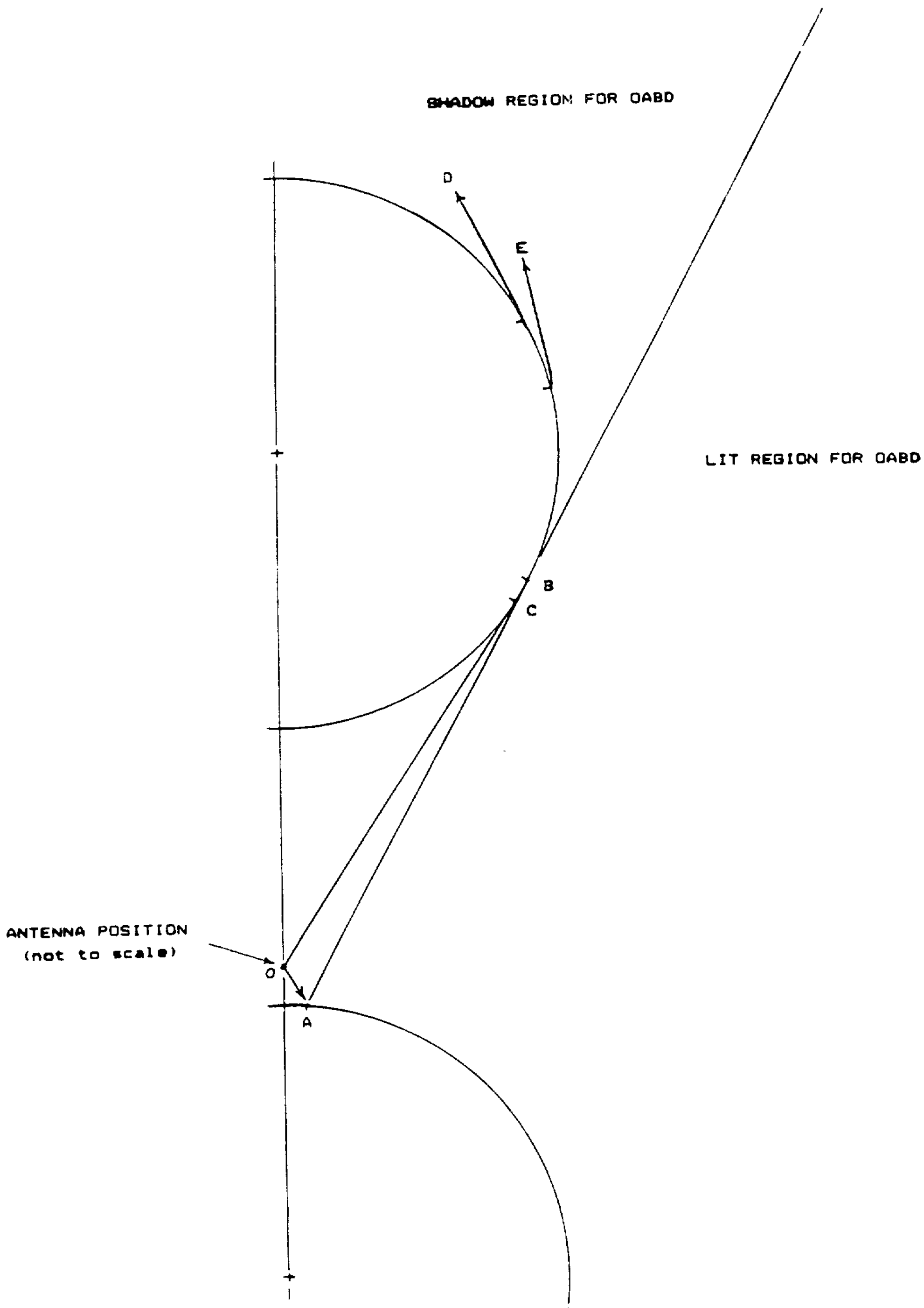


Figure 14. Reflection and diffraction ray paths for 2-cylinder configuration.

The ray path OABD includes a second scattering mechanism. The direct ray proceeds from O to a reflection point A on cylinder 1, thence to a tangent point on cylinder 2. From this point it diffracts around the cylinder to the second tangent point from which it is radiated toward D. Both reflection and diffraction are involved, so that in this case we have the two-step reflection-diffraction mechanism.

For smaller values of φ, multiple reflections between the two cylinders, followed by diffraction from cylinder 1 would occur. Since the code can accommodate only a two-step process, a reflection-reflection-diffraction mechanism would not be computed, nor would any higher order process. The absence of the contributions of these mechanisms appears as an abrupt drop in the computed pattern amplitude at the edge of the shadow zone. This effect can be seen at angles A and B in Figure 13.

The amplitude changes observed at points C and D in Figure 13 occur for the same reasons. Figure 15 depicts the ray paths involved at these angles. Path OBDF consists of a reflection at B followed by a diffraction at D, producing the final ray toward F (reflection-diffraction). However, the path OACEG involves two reflections followed by a diffraction (reflection-reflection-diffraction), a three-step process which the code cannot handle. This contribution is not computed in the shadow zone of Figure 15, and its abrupt loss at angle C in the pattern (Figure 13) produces a sudden change in amplitude.

A different arrangement was selected to produce the pattern shown in Figure 16. Inspection of that pattern reveals the same type of phenomena as those discussed for the previous arrangement.

6.1.2.3.2 Two-cylinder configuration using SRB and ET diameters.

Two patterns were computed for this two-cylinder case. The only difference between the conditions used for computing the two patterns is the relative position of the antenna in the plane normal to the two cylinder axes.

Two interesting features are seen in Figure 17 (A). The pattern amplitude drops sharply at about 66 degrees. This drop is caused by shadowing by the external tank, as shown in Figure 18. A second feature appears at 306 degrees. An interference pattern suddenly begins at that angle and continues through the 306-360 degree region. The mechanism that produces the interference may be seen in Figure 18. The following scattering effects occur in the vicinity of the 306-degree angle:

(1) The direct ray from the antenna is seen both above and below this angle.

(2) The direct ray OA is reflected at A for angles up to that shown in Figure 18. For larger angles, the direct ray is

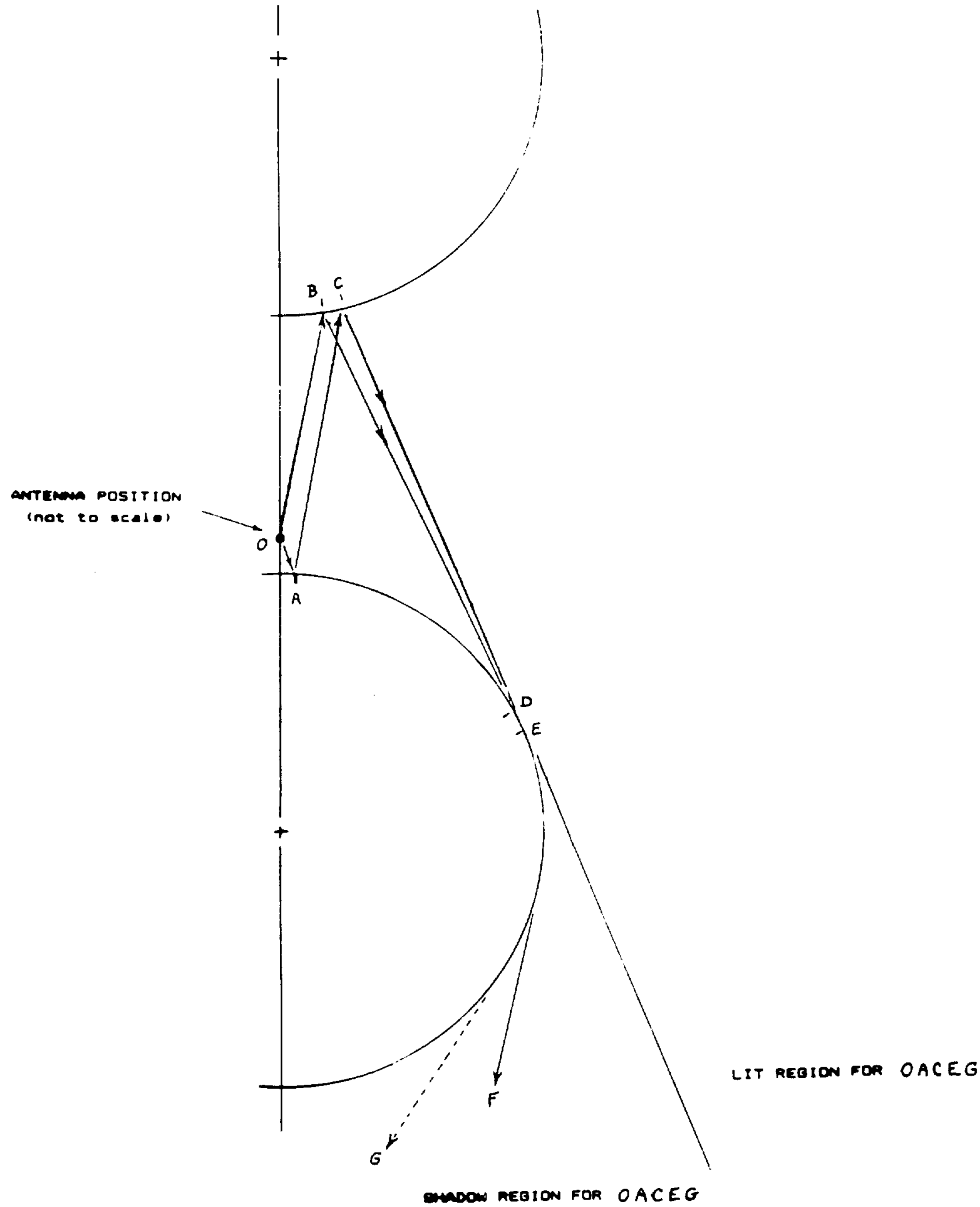


Figure 15. Reflection and diffraction ray paths for 2-cylinder configuration.

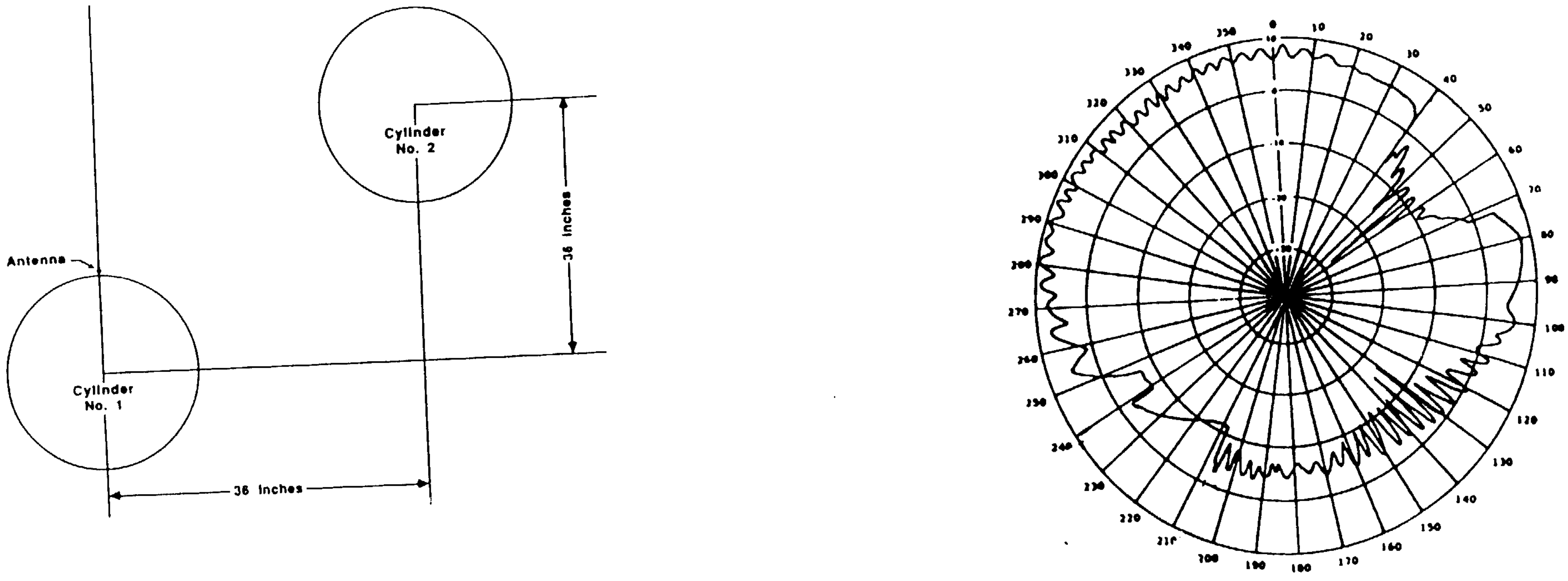
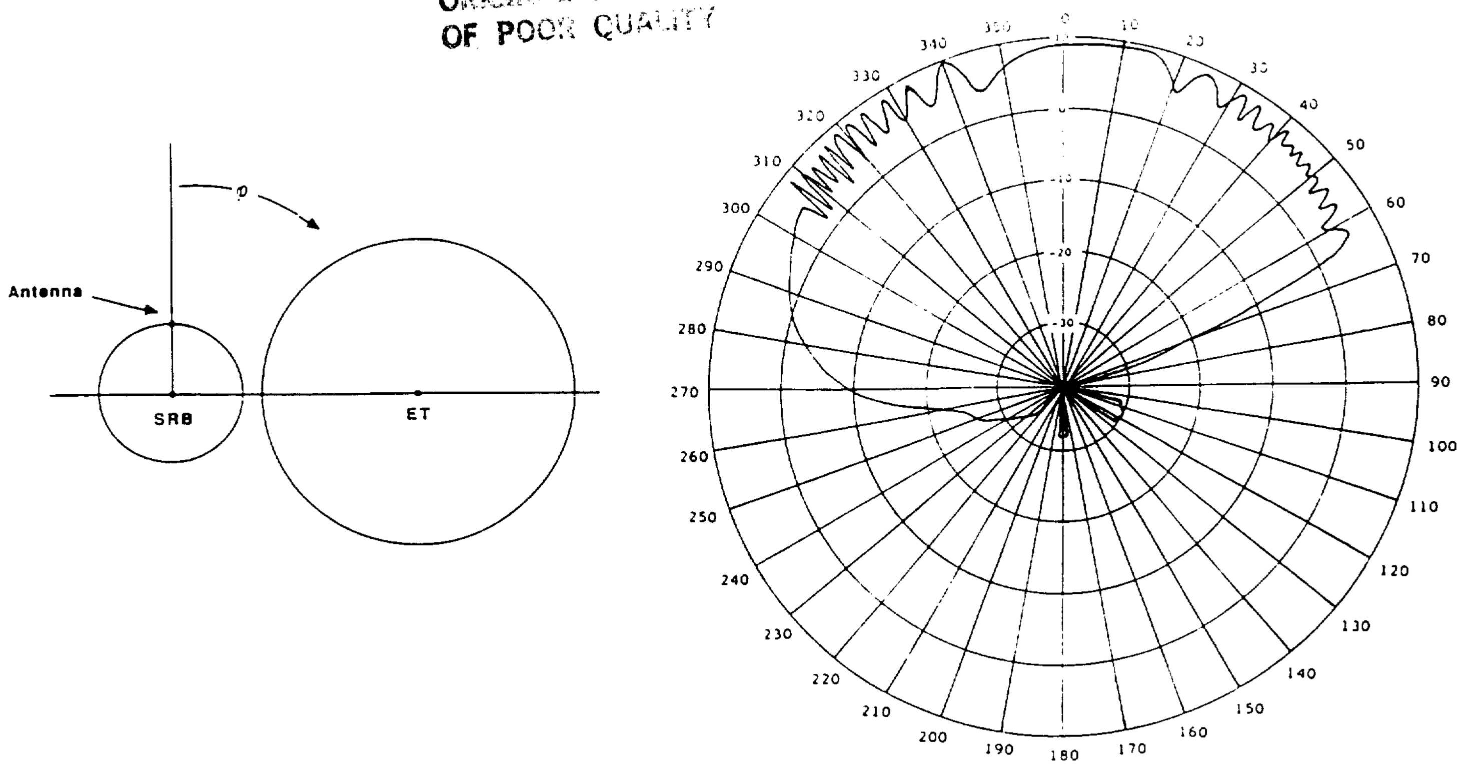
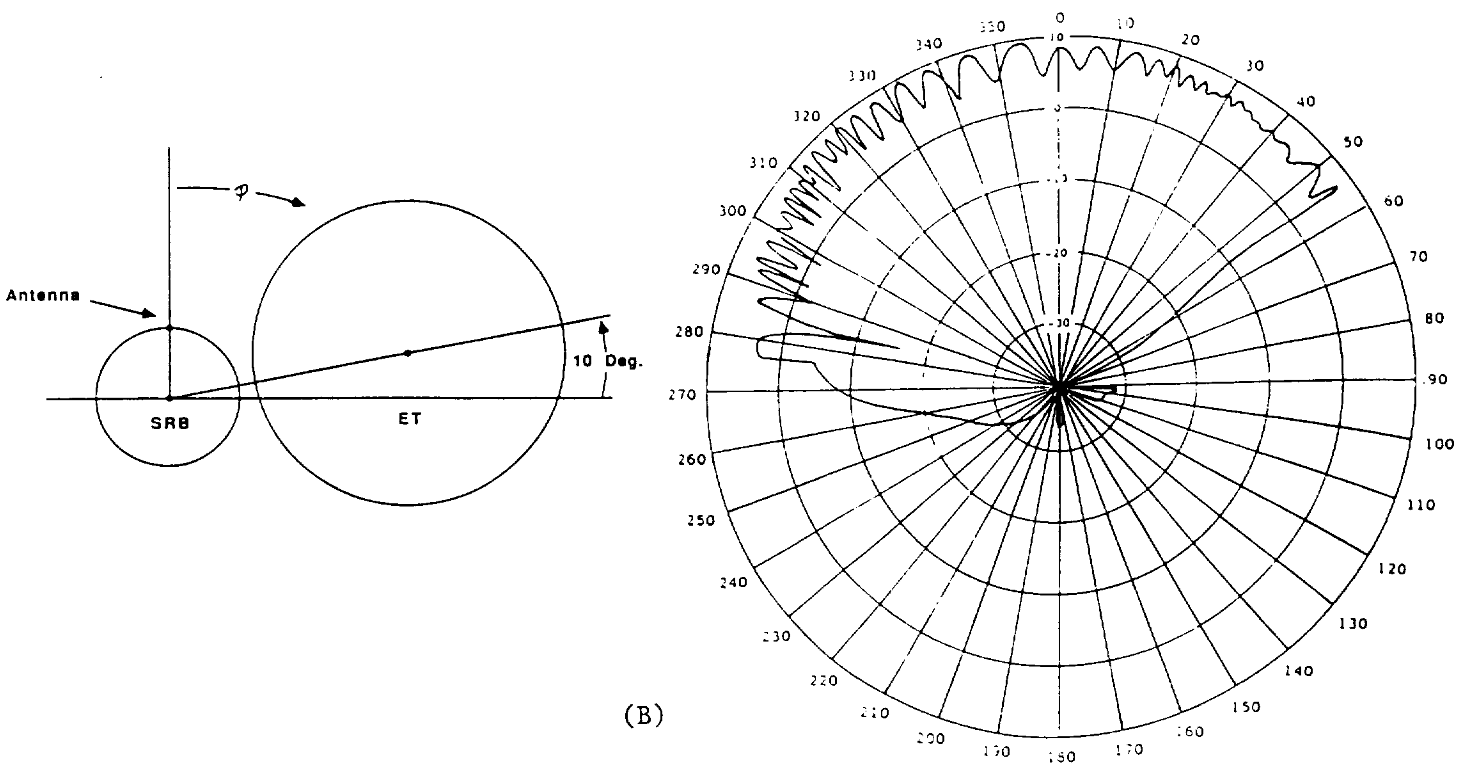


Figure 16. Pattern of antenna model, configuration 1, with 2-cylinder configuration. Cylinder diameters = 24 inches.



(A)



(B)

Figure 17. Patterns of antenna model, configuration 1, using cylinders which represent the Shuttle Solid Rocket Booster and external tank.

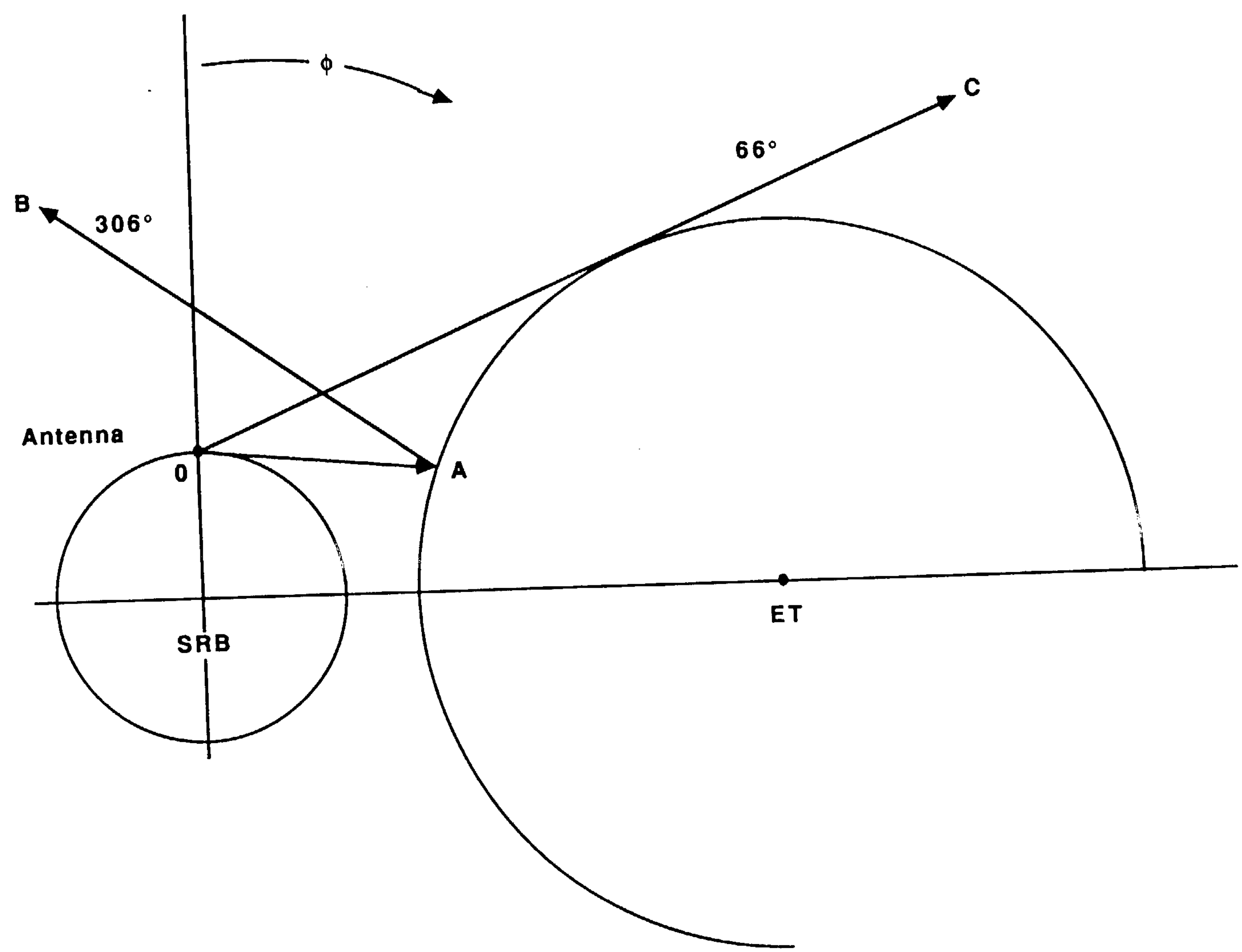


Figure 18. Reflected ray paths for SRB-ET configuration.

shadowed by the SRB cylinder body, but the diffracted ray produced by its travel around the cylinder is then reflected from the ET. This is a two-step process and is computed.

(3) When ray OA exceeds the angle shown in the sketch, multiple-scattering combinations come into play which involve more than the two-step process accommodated by the code. The contributions of these mechanisms are absent in the computation.

The cessation of the interference process occurs when conditions are such that contributions from the ET no longer combine with the direct ray to produce an interference pattern.

The scattering mechanisms that produce the pattern of Figure 17 (B) are shown in Figure 19. The same phenomena may be seen occuring in this case as were observed for the case of Figure 17 (A), but involving different angles and amplitudes.

7.0 CONCLUSIONS

A review of existing computer codes for calculating the radiation patterns of antennas on complex launch and spacecraft structures has resulted in the selection of two codes which are deemed to be best suited to the needs of the Marshall Space Flight Center. These codes were obtained from the Ohio State University. They are entitled NEC-BSC and ESP3. The NEC-BSC code is based on the the Uniform Theory of Diffraction, a refinement of the Geometrical Theory of Diffraction. The NEC-BSC code is well suited to problems involving scattering structures that are large in terms of wavelengths, while the ESP3 code is best suited to use with small scatterers. Thus, the two codes are complementary.

Certain deficiencies have been identified in the NEC-BSC code as they relate to the use of the code for solution of problems expected to be encountered by the MSFC antenna design personnel.

The potential use of the NEC-BSC code in solving an antenna design problem associated with the Space Shuttle has been examined and assessed. It is concluded that the code can be very usefully employed for evaluating the scattering mechanisms involved in that problem, and to a limited degree, may be used to compute the patterns produced by the complete shuttle configuration.

Both of the selected codes should prove highly useful when used in conjunction with measurements performed on an antenna pattern range. Validation and analysis of measured patterns, determination of required features for an experimental scale model and study of individual scattering processes during an antenna design study will prove to be useful tools in the design process.

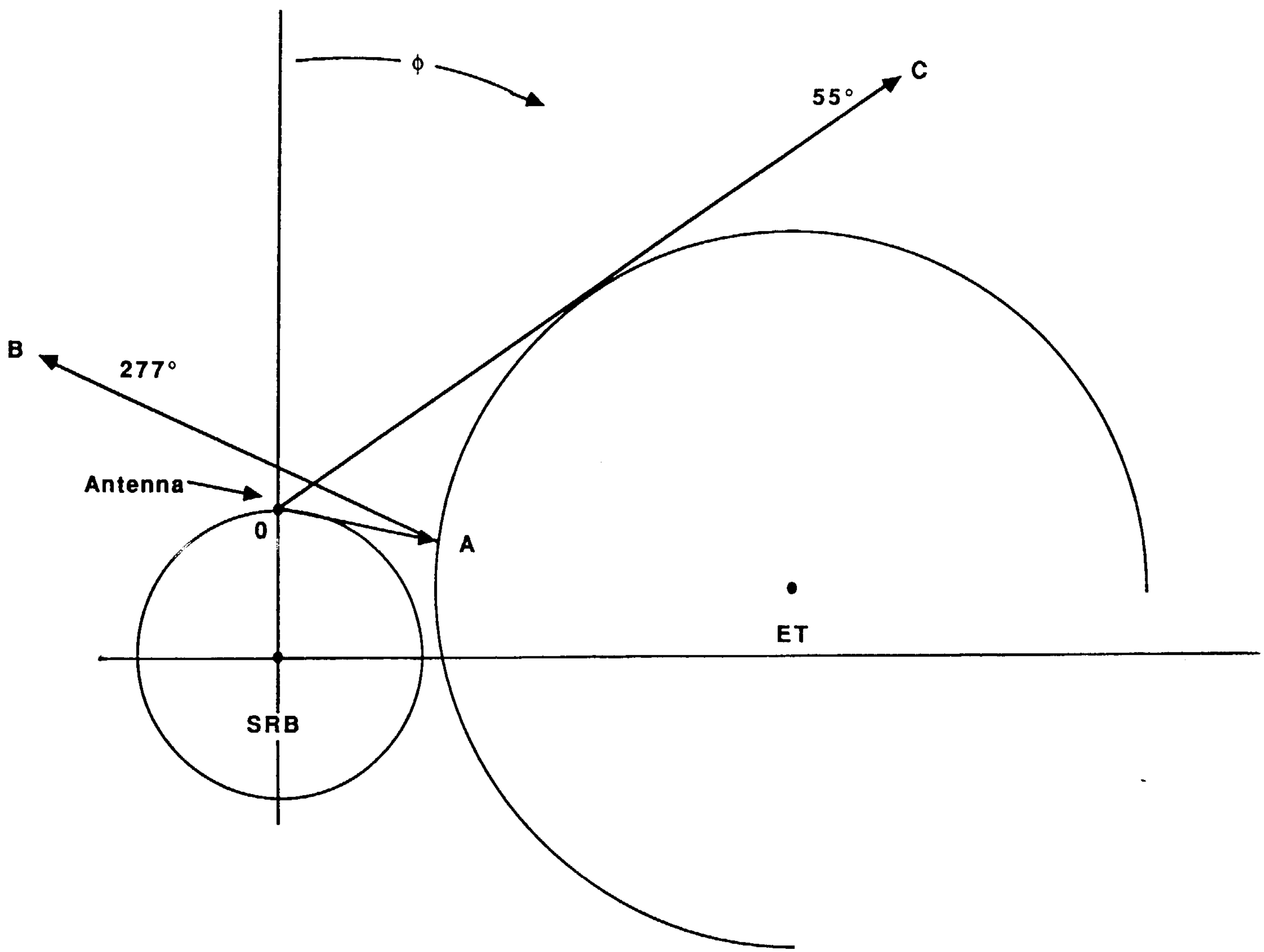


Figure 19. Reflected ray paths for SRB-ET configuration.

APPENDIX A

DATA INPUT CODES

&

COMMAND FILES

COMMAND FILES

SCAT 1

```
$ ASSIGN/USER SYS$COMMAND SYS$INPUT
$ RUN INSCAT
$ ASSIGN FOR005.DAT SYS$INPUT
$ ASSIGN OUTPUT.DAT SYS$OUTPUT
$ RUN SCAT
$ DEASSIGN SYS$OUTPUT
$ DEASSIGN SYS$INPUT
```

SCAT 2

```
$ ASSIGN FOR005.DAT SYS$INPUT
$ ASSIGN OUTPUT.DAT SYS$OUTPUT
$ RUN SCAT
$ DEASSIGN SYS$OUTPUT
$ DEASSIGN SYS$INPUT
```

PATCH 1

```
$ ASSIGN/USER SYS$COMMAND SYS$INPUT
$ RUN INDAT4
$ ASSIGN FOR010.DAT SYS$INPUT
$ ASSIGN OUTDAT.DAT SYS$OUTPUT
$ RUN ESP3
$ DEASSIGN OUTDAT.DAT SYS$OUTPUT
$ DEASSIGN FOR010.DAT SYS$INPUT
```

PATCH 2

```
$ ASSIGN FOR010.DAT SYS$INPUT
$ ASSIGN OUTDAT.DAT SYS$OUTPUT
$ RUN ESP3
$ DEASSIGN OUTDAT.DAT SYS$OUTPUT
$ DEASSIGN FOR010.DAT SYS$INPUT
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
      PROGRAM INSCAT
C
C     THIS PROGRAM PROVIDES AN INTERACTIVE MEANS FOR ENTERING INPUT
C     DATA INTO THE OHIO STATE UNIVERSITY NEC-BSC PROGRAM.  THE
C     REQUESTED PARAMETER VALUES ARE WRITTEN TO A DATA FILE FOR005.DAT
C     TO BE CALLED BY PROGRAM "SCAT".
C
C     THIS PROGRAM WAS WRITTEN BY:
C
C
C           J. WARREN HARPER
C           APPLIED RESEARCH, INC.
C           5025 BRADFORD BLVD.
C           HUNTSVILLE, ALABAMA 35805
C
      CHARACTER *3 STRING
      CHARACTER *36 INPUT
      CHARACTER *2 NZERO
C
      OPEN(1,FILE='FOR005.DAT',STATUS='NEW')
C
      STRING = 'CE: '
      WRITE(*,1)
    1 FORMAT(1H$,'Enter Comment (max 36 chars)    ')
      READ(*,2)INPUT
    2 FORMAT(A36)
      WRITE(1,3)STRING,INPUT
    3 FORMAT(A3,A36)
C
      WRITE(*,200)
  200 FORMAT(1X,'ENTER NUMBER INDICATING UNITS TO BE USED -'/15X,'1 =  M
     1ETERS'/15X,'2 = FEET'/15X,'3 = INCHES'/)
      READ(*,2) INPUT
      STRING='UN: '
      WRITE(1,9) STRING
      WRITE(1,2) INPUT
C
      WRITE(*,5)
    5 FORMAT(1X,'FREQUENCY IN GHZ.?')
      READ(*,2) INPUT
      STRING='FR: '
      WRITE(1,9) STRING
      WRITE(1,2) INPUT
    7 FORMAT(I2)
    8 FORMAT(I1,1X,A1)
    9 FORMAT(A3)
C
      WRITE(*,10)
   10 FORMAT(1X,'    *** ORIENTATION OF PATTERN AXES ***'/)
      STRING='PD: '
      WRITE(*,15)
   15 FORMAT(1X,'THETA, PHI FOR Z AXIS, THETA, PHI FOR X AXIS (1 LINE)')
      READ(*,2) INPUT
      WRITE(1,9) STRING
      WRITE(1,2) INPUT
C
C                    *** TYPE OF PATTERN CUT ***
C
      WRITE(*,210)
  210 FORMAT(1X,'TYPE OF PATTERN CUT DESIRED (GREAT CIRCLE OR CONICAL)'/
     1/'            T = CONICAL CUT (CONSTANT THETA)'/'           F = GREAT
```

```
   2 CIRCLE CUT (CONSTANT PHI)'///' ENTER T OR F, FOLLOWED BY VALUE OF
   3THE FIXED ANGLE, ON ONE LINE.')
    READ(*,2) INPUT
    WRITE(1,2) INPUT
C
C                    *** ANGULAR RANGE DESIRED ***
C
    WRITE(*,220)
220 FORMAT(1X,'ANGULAR RANGE DESIRED FOR PATTERN:  INITIAL ANGLE, FINAL
   1 ANGLE, ANGULAR INCREMENT')
    READ(*,2) INPUT
    WRITE(1,2) INPUT
C
C                          *** PLATE GEOMETRY ***
C
    WRITE(*,40)
 40 FORMAT(1X'HOW MANY PLATES?')
    READ(*,*) NOPLT
    IF(NOPLT.LT.1) GOTO 82
C
    STRING='PG:'
    DO 80 MP=1,NOPLT
    WRITE(1,9) STRING
C
    WRITE(*,50) MP
 50 FORMAT(1X,'PLATE NUMBER ',I2,/' HOW MANY CORNERS?')
    READ(*,7) NUM
    NZERO='0'
    WRITE(1,8) NUM,NZERO
C
    DO 70 ME=1,NUM
    WRITE(*,60) ME
 60 FORMAT(1X,'X,Y,Z POSITION OF CORNER NUMBER ',I2)
    READ(*,2) INPUT
    WRITE(1,2) INPUT
 70 CONTINUE
 80 CONTINUE
C
C                  *** CYLINDER GEOMETRY ***
C
 82 WRITE(*,84)
 84 FORMAT(1X,'HOW MANY CYLINDERS?')
    READ(*,*) NCYL
    IF(NCYL.LT.1) GOTO 99
    DO 94 N=1,NCYL
    STRING='CG:'
    WRITE(1,9) STRING
    WRITE(*,86) N
 86 FORMAT(1X,'LOCATION (X,Y,Z) OF ORIGIN, CYLINDER NO.  ',I1)
    READ(*,2) INPUT
    WRITE(1,2) INPUT
C
    WRITE(*,88) N
 88 FORMAT(1X,'CYLINDER NO.  ',I1,' ORIENTATION'/1X,'THETA-Z, PHI-Z, TH
   1ETA-X, PHI-X')
    READ(*,2) INPUT
    WRITE(1,2) INPUT
C
    WRITE(*,90)
 90 FORMAT(1X,'CYLINDER RADII:  RX, RY')
```

```
      READ(*,2) INPUT
      WRITE(1,2) INPUT
C
      WRITE(*,92)
   92 FORMAT(1X,'POSITIONS & ANGLES OF END CAPS'/1X,'POSITION & ANGLE FO
     1R NEGATIVE END, POSITION & ANGLE FOR POSITIVE END.')
      READ(*,2) INPUT
      WRITE(1,2) INPUT
   94 CONTINUE

C
C                     *** SOURCE GEOMETRY ***
C
   99 WRITE(*,100)
  100 FORMAT(1X,'         *** SOURCE GEOMETRY ***'/)
      WRITE(*,110)
  110 FORMAT(1X,'HOW MANY SOURCE ELEMENTS?')
      READ(*,*) NWIRES
      STRING='SG: '
C
      DO 180 MS=1,NWIRES
      WRITE(1,9) STRING
      WRITE(*,120) MS
  120 FORMAT(1X,'SOURCE ELEMENT NUMBER',I2/)
      WRITE(*,130)
  130 FORMAT(1X,'X,Y,Z POSITION OF ELEMENT CENTER?')
      READ(*,2) INPUT
      WRITE(1,2) INPUT
C
      WRITE(*,140)
  140 FORMAT(1X,'THETA & PHI ANGLES FOR LENGTH & WIDTH VECTORS'/'
     1(THETA-L, PHI-L, THETA-W, PHI-W')
      READ(*,2) INPUT
      WRITE(1,2) INPUT
C
      WRITE(*,160) MS
  160 FORMAT(1X,'TYPE, LENGTH AND WIDTH OF ELEMENT',I2/'          TYPE:'/'
     1            -1     UNIFORM CURRENT DISTRIBUTION'/'               -2
     2PIECEWISE SINUSOIDAL DISTRIBUTION'/)
      READ(*,2) INPUT
      WRITE(1,2) INPUT
C
      WRITE(*,170) MS
  170 FORMAT(1X,'EXCITATION (MAGNITUDE, PHASE) FOR ELEMENT',I2)
      READ(*,2) INPUT
      WRITE(1,2) INPUT
  180 CONTINUE
      STRING='XQ: '
      WRITE(1,9) STRING
      STRING='EN: '
      WRITE(1,9) STRING
      CLOSE (1)
      END
```

```
      PROGRAM INDAT4
C
C     THIS PROGRAM PROVIDES AN INTERACTIVE MEANS FOR ENTERING INPUT
C     DATA INTO THE OHIO STATE UNIVERSITY ESP3 PROGRAM.  THE REQUESTED
C     PARAMETER VALUES ARE WRITTEN TO A DATA FILE FOR010.DAT IN THE
C     PROPER ORDER TO BE CALLED BY ESP3.
C
C     THIS PROGRAM WAS WRITTEN BY:
C
C           J. WARREN HARPER
C           APPLIED RESEARCH, INC.
C           5025 BRADFORD AVE.
C           HUNTSVILLE, ALABAMA   35805
C
      DIMENSION NCNRS(10)
      DIMENSION X(10),Y(10),Z(10)
      DIMENSION NPLA(10),BDSK(10),VGA(10),ZLDA(10)
      DIMENSION PCN(3,10,10),IA(10),IB(10),SEGM(10)
      DIMENSION IREC(10),IPN(10),IGS(10),NAS(10)
      DIMENSION NSA(10),VG(10),ZLD(10),IFM(10)
      DIMENSION IABFP(10),IABAP(10)
      DIMENSION VLG(10),ZL(10)
C
      CHARACTER *1 USEWRS,GEOPRT,DFLT,FARZN,USEPLT,MCOUPL,WRTIMP
      CHARACTER *1 CHFREQ,CHGPAT,CHGRAD,CHGCON
C
      COMPLEX VLG
      COMPLEX ZL
      COMPLEX VGA
      COMPLEX ZLDA
C
      WRITE(5,10)
   10 FORMAT(' THIS PROGRAM (ESP3) IS BASED ON THE METHOD OF MOMENTS')
      WRITE(5,20)
   20 FORMAT('             ************************')
      WRITE(5,30)
   30 FORMAT(' ')
C
      WRITE(5,2000)
 2000 FORMAT(1X,'DO YOU WISH TO CHANGE EXISTING INPUT FILE? Y OR N')
      READ(5,50) CHGFIL
      IF(CHGFIL.EQ.'N'.OR.CHGFIL.EQ.'n') GOTO 8
      ICHG=1
C
C     READ IN VALUES FROM EXISTING DATA FILE
C
      READ(10,*) NGO,NPRINT,NRUNS,NWGS,IWR,IWRZT,INT,INTP,INTD,INWR,IRGM
     1,IFIL
      READ(10,*) IFE,IPFE,NDFE,PHFE
      READ(10,*) IFA,IPFA,NDFA,THFA
      READ(10,*) ISE,IPSE,NDSE,PHSE,THIN,PHIN
      READ(10,*) ISA,IPSA,NDSA,THSA
      READ(10,*) FMC,CMM,A
      IF(USEPLT.EQ.'N'.OR.USEPLT.EQ.'n') GOTO 1530
      READ(10,*) NPLTS
      DO 1520 NPL=1,NPLTS
      READ(10,*) NCNRS(NPL),SEGM(NPL),IREC(NPL),IPN(IPL),IGS(NPL)
      DO 1510 NCNR=1,NCNRS(NPL)
      READ(10,*) PCN(1,NCNR,NPL),PCN(2,NCNR,NPL),PCN(3,NCNR,NPL)
 1510 CONTINUE
```

```
 1520 CONTINUE
 1530 IF(USEWRS.EQ.'N'.OR.USEWRS.EQ.'n') GOTO 810
      READ(10,*) IWRZM,IRDZM
      READ(10,*) NM,NP,NAT,NFPT,NFS1,NFS2
C
      DO 1550 I=1,NP
      READ(10,*) X(I),Y(I),Z(I)
 1550 CONTINUE
C
      DO 1560 I=1,NM
      READ(10,*) IA(I),IB(I)
 1560 CONTINUE
C
      DO 1570 I=1,NFPT
      READ(10,*) IFM(I),IABFP(I),VLG(I),ZL(I)
 1570 CONTINUE
C
      DO 1580 I=1,NAT
      READ(10,*) NAS(I),IABAP(I),NPLA(I),VGA(I),ZLDA(I),BDSK(I)
 1580 CONTINUE
      REWIND 10
C
C     END OF READING OF DATA FILE
C
      WRITE(*,2001)
 2001 FORMAT(1X,'CHANGE FREQUENCY? Y OR N')
      READ(*,50) CHFREQ
      IF(CHFREQ.EQ.'N'.OR.CHFREQ.EQ.'n') GOTO 2002
      CALL RCHNGE(FMC,0.,0.,1,ICHG)
      READ(*,*) FMC
      WRITE(*,3200)
 3200 FORMAT(/)
C
 2002 IF(USEWRS.EQ.'N'.OR.USEWRS.EQ.'n') GOTO 2006
      WRITE(*,2003)
 2003 FORMAT(1X,'CHANGE WIRE RADIUS? Y OR N')
      READ(*,50) CHGRAD
      IF(CHGRAD.EQ.'N'.OR.CHGRAD.EQ.'n') GOTO 2004
      CALL RCHNGE(A,0.,0.,1,ICHG)
      READ(*,*) A
      WRITE(*,3200)
C
 2004 WRITE(*,2005)
 2005 FORMAT(1X,'CHANGE WIRE CONDUCTIVITY? Y OR N')
      READ(*,50) CHGCON
      IF(CHGCON.EQ.'N'.OR.CHGCON.EQ.'n') GOTO 2006
      CALL RCHNGE(CMM,0.,0.,1,ICHG)
      READ(*,*) CMM
      WRITE(*,3200)
C
 2006 WRITE(*,2007)
 2007 FORMAT(1X,'CHANGE PATTERN DATA? Y OR N')
      READ(*,50) CHGPAT
      IF(CHGPAT.EQ.'N'.OR.CHGPAT.EQ.'n') GOTO 2009
      WRITE(*,2012)
 2012 FORMAT(1X,'SPECIFY TYPE OF PATTERN CUT'/10X,'1  GREAT-CIRCLE CUT (
     1VARIABLE THETA)'/10X,'2  CONICAL CUT (VARIABLE PHI)'/)
      CALL ICHNGE(ICUT,0,0,1,ICHG)
      READ(*,*) ICUT
      WRITE(*,3200)
```

```
C
      WRITE(*,2013)
 2013 FORMAT(1X,'VALUE OF CONSTANT ANGLE?')
      CALL RCHNGE(CONANG,0.,0.,1,ICHG)
      READ(*,*) CONANG
      WRITE(*,2014)
 2014 FORMAT(1X,'ANGLE INCREMENT?')
      CALL RCHNGE(ANGINC,0.,0.,1,ICHG)
      READ(*,*) ANGINC
      WRITE(*,3200)
C
 2009 WRITE(5,2010)
 2010 FORMAT(1X,'CHANGE PLATE DATA? Y OR N')
      READ(5,50) MODPLT
      IF(MODPLT.EQ.'N'.OR.MODPLT.EQ.'n') GOTO 2055
      WRITE(5,2020)
 2020 FORMAT(1X,'ADD A PLATE? Y OR N')
      READ(5,50) ADDPLT
      IF(ADDPLT.EQ.'N'.OR.ADDPLT.EQ.'n') GOTO 2030
      NPLTS=NPLTS+1
      NPL=NPLTS
      CALL PLATE(NPL,NCNRS,SEGM,IREC,IPN,IGS,PCN,ICHG)
 2030 WRITE(5,2040)
 2040 FORMAT(1X,'CHANGE A PLATE? Y OR N')
      READ(5,50) CHGPLT
      IF(CHGPLT.EQ.'N'.OR.CHGPLT.EQ.'n') GOTO 2055
      WRITE(5,2050)
 2050 FORMAT(1X,'WHICH PLATE?')
      READ(5,*) NPL
      CALL PLATE(NPL,NCNRS,SEGM,IREC,IPN,IGS,PCN,ICHG)
C
 2055 WRITE(5,2060)
 2060 FORMAT(1X,'CHANGE WIRE DATA? Y OR N')
      READ(5,50) CHGWIR
      IF(CHGWIR.EQ.'N'.OR.CHGWIR.EQ.'n') GOTO 810
      CALL WIRE(NM,NP,NAT,NFPT,NSF1,NSF2,ICHG)
      GOTO 810
C
C      ********* END OF CHANGE SECTION; BEGIN ORIGINAL INPUT *********
C
    8 ICHG=0
      WRITE(5,12)
   12 FORMAT(1X,'DO YOU WISH TO SPECIFY ANY OF THE FOLLOWING PARAMETERS?
     1 (Y or N)'/)
      WRITE(5,14)
   14 FORMAT(10X,'* NUMBER OF RUNS TO BE MADE'/10X,'* PRINT OF MODAL CUR
     1RENTS'/10X,'* PRINT OF IMPEDANCE MATRIX'/10X,'* NUMBER OF SIMPSONS
     2-RULE INTERVALS FOR:'/15X,'WIRE-TO-WIRE IMPEDANCES'/15X,'SURFACE-P
     3ATCH MONOPOLES'/15X,'DISK MONOPOLES'//)
C
      READ(5,50)DFLT
C
      IF(DFLT.EQ.'Y'.OR.DFLT.EQ.'y') GOTO 1005
C
C        --- APPLY DEFAULT VALUES ---
C    READ 1:
      NRUNS=1
      NWGS=1
      IWR=0
      IWRZT=1
```

```
      INT=4
      INTP=6
      INTD=18
      IRGM=1
      GOTO 35
C
 1005 WRITE(5,1010)
 1010 FORMAT(/1X,'HOW MANY RUNS DO YOU WISH TO MAKE?')
      READ(5,*) NRUNS
      WRITE(5,1020)
 1020 FORMAT(/1X,'NUMBER OF WIRE GEOMETRIES FOR EACH RUN?')
      READ(5,*) NWGS
      WRITE(5,1025)
 1025 FORMAT(/1X,'MODAL CURRENT PRINTOUT:'/6X,'0  NO MODAL CURRENT PRINT
     1OUT'/6X,'1  MODAL CURRENTS PLUS WIRE/PLATE GEOMETRY PRINTED')
      READ(5,*) IWR
C
      WRITE(5,1030)
 1030 FORMAT(/1X,'WRITE IMPEDANCE MATRIX IN PRINTED OUTPUT FILE? Y OR N'
     1)
      READ(5,50)WRTIMP
C
      WRITE(5,*)WRTIMP
C

      IF(WRTIMP.EQ.'Y'.OR.WRTIMP.EQ.'y') GOTO 1032
      IWRZT=0
      GOTO 1036
 1032 IWRZT=1
 1036 CONTINUE
C
      WRITE(5,*)IWRZT
C
      WRITE(5,1040)
 1040 FORMAT(/1X,'NUMBER OF SIMPSONS-RULE INTEGRATION INTERVALS:'//1X,'F
     1OR WIRE-TO-WIRE IMPEDANCES?')
      READ(5,*) INT
      WRITE(5,1050)
 1050 FORMAT(/1X,'FOR SURFACE-PATCH MODULES?')
      READ(5,*) INTP
      WRITE(5,1060)
 1060 FORMAT(/1X,'FOR DISK MONOPOLES?')
      READ(5,*) INTD
      WRITE(5,1070)
 1070 FORMAT(//1X,'HOW IS THE WIRE GEOMETRY DEFINED?'/10X,'0  BY SUBROUT
     1INE WGEOM'/10X,'1  DEFINED VIA THE INPUT FILE')
      READ(5,*) IRGM
C
C           --- INPUT NON-DEFAULT INFORMATION ---
C
   35 WRITE(5,40)
   40 FORMAT(/1X,'DOES THE MODEL CONTAIN WIRES? (Y or N)')
      READ(5,50) USEWRS
      WRITE(5,45)
   45 FORMAT(/1X,'DOES THE MODEL CONTAIN PLATES? (Y or N)')
      READ(5,50) USEPLT
C
   50 FORMAT(A1)
      IF(USEWRS.EQ.'Y'.OR.USEWRS.EQ.'y') THEN
         INWR=1
```

```fortran
      ENDIF
C
      WRITE(5,60)
   60 FORMAT(/1X,'SPECIFY REQUIRED OUTPUT: '/10X,'1  PRINT WIRE & PLATE G
     1EOMETRY'/10X,'2  PRINT INPUT PARAMETERS & WIRE/PLATE GEOMETRY'/10X
     2,'3  PRINT NOTHING')
C
      READ(5,*) NPRINT
C
      WRITE(5,70)
   70 FORMAT(/1X,'DO YOU WANT TO PRINT INPUT DATA BEFORE COMPUTING?')
      READ(5,50) IFIRST
      IF(IFIRST.EQ.'Y'.OR.IFIRST.EQ.'y') THEN
          NGO=0
          ELSE
          NGO=1
      ENDIF
C
      WRITE(5,80)
   80 FORMAT(/1X,'SPECIFY TYPE OF PATTERN CUT'/10X,'1  GREAT-CIRCLE CUT
     1(VARIABLE THETA)'/10X,'2  CONICAL CUT (VARIABLE PHI)'/)
      READ(5,*) ICUT
      WRITE(5,90)
   90 FORMAT(/1X,'FAR-ZONE ANTENNA PATTERN? (Y or N)')
      READ(5,50) FARZN
      WRITE(5,110)
  110 FORMAT(/1X,'VALUE OF CONSTANT ANGLE: ')
      READ(5,*) CONANG
      WRITE(5,130)
  130 FORMAT(/1X,'ANGLE INCREMENT?')
      READ(5,*) ANGINC
      WRITE(5,120)
  120 FORMAT(/1X,'DO YOU WANT AN OUTPUT FOR PLOTTING?  (Y or N)')
      READ(5,50) PLTOUT
C
      IF(FARZN.EQ.'N'.OR.FARZN.EQ.'n') GOTO 150
C
C        --- PARAMETERS SET FOR PLANE-WAVE SCATTER CASE ---
C
      ISE=0
      IPSE=0
      NDSE=1
      PHSE=1.0
      THIN=1.0
      PHIN=1.0
      ISA=0
      IPSA=0
      NDSA=1
      THSA=1
C
C     --- CONSTANT ANGLE VALUE IS SET FOR EITHER PATTERN CUT ---
C
      PHFE=CONANG
      THFA=CONANG
C
C              --- TYPE OF PATTERN CUT IS SET ---
C
      IF(ICUT.EQ.1) THEN
        IFE=1
        IFA=0
```

```
        ELSE
          IFE=0
          IFA=1
        ENDIF
C
C          --- OUTPUT DESIGNATION & ANGLE INCREMENT VALUE ---
C
      IF(PLTOUT.EQ.'Y'.OR.PLTOUT.EQ.'y') THEN
          IPFE=1
          IPFA=1
        ELSE
          IPFE=0
          IPFA=0
       ENDIF
C
      NDFE=ANGINC
      NDFA=ANGINC
C
      GOTO 175
C
C                PARAMETER VALUES SET FOR FAR-ZONE RADIATION
C                   PATTERN FOR BOTH TYPES OF PATTERN CUT
C
  150 IFE=0
      IPFE=0
      NDFE=1
      PHFE=1.0
      IFA=0
      IPFA=0
      NDFA=1
      THFA=1.0
C
C     --- INPUT MATRIX DOES NOT EXIST FOR THIS CASE ---
      IWRZT=0
C
C        ---  PLATES ARE MODELED AS PERFECT CONDUCTORS ---
      CMM=-1.0
C
C           --- "WIRE RADIUS" SET TO .001 FOR PLATE ---
      A=.001
C
C         --- INFORMATION INPUT FOR PLANE-WAVE SCATTER ---
C
      WRITE(5,160)
  160 FORMAT(/1X,'SPECIFY TYPE OF SCATTER COMPUTATION:'/10X,'1  BACKSCAT
     1TER'/10X,'2  BISTATIC SCATTER'/10X,'3  FORWARD SCATTER')
C
      READ(5,*) ITYPE
      IF(ICUT.EQ.1) THEN
          ISE=ITYPE
          ISA=0
        ELSE
          ISE=0
          ISA=ITYPE
        ENDIF
C
      IF(PLTOUT.EQ.'Y'.OR.PLTOUT.EQ.'y') THEN
          IPSE=1
          IPSA=1
        ELSE
```

```
            IPSE=0
            IPSA=0
         ENDIF
C
C       -- INPUT ANGLE INCREMENTS FOR PLANE-WAVE SCATTER ---
C
      NDSE=ANGINC
      NDSA=ANGINC
C
C       --- INPUT CONSTANT ANGLE FOR PLANE-WAVE SCATTER ---
C
      PHSE=CONANG
      THSA=CONANG
C
C                --- INPUT ANGLE OF INCIDENCE ---
C
      WRITE(5,170)
  170 FORMAT(/1X,'WHAT IS THE ANGLE OF INCIDENCE? (THETA, PHI)')
      READ(5,*) THIN,PHIN
C
C                 --- INPUT FREQUENCY ---
C
  175 WRITE(5,180)
  180 FORMAT(1X,'FREQUENCY IN MEGAHERTZ?')
      READ(5,*) FMC
C
C       --- INPUT WIRE CONDUCTIVITY & RADIUS IF WIRES USED ---
C
      IF(USEWRS.EQ.'N'.OR.USEWRS.EQ.'n') GOTO 210
C
      WRITE(5,190)
  190 FORMAT(1X,'WIRE CONDUCTIVITY IN MEGAMHOS/METER?')
      READ(5,*) CMM
      WRITE(5,200)
  200 FORMAT(1X,'WIRE RADIUS IN METERS?')
      READ(5,*) A
C
      GOTO 215
C
C       --- SUPPLY FICTITIOUS NUMBERS FOR WIRE PARAMETERS ---
C
  210 CMM=-1.0
      A=0.001
C
  215 IF(USEPLT.EQ.'N'.OR.USEPLT.EQ.'n') GOTO 300
C
C                --- INPUT PLATE INFORMATION ---
C
      WRITE(5,220)
  220 FORMAT(/1X,'HOW MANY PLATES?')
      READ(5,*) NPLTS
C
      WRITE(5,225)
  225 FORMAT(/1X,'INPUT TYPE OF PLATE TEST MODE:'/10X,'0  FULL-SURFACE P
     1ATCH MODE'/10X,'1 FILAMENTARY TEST MODE')
      READ(5,*) IFIL
C
      WRITE(5,230)
  230 FORMAT(/1X,'PLATE INFORMATION --'/)
C
```

```
      DO 420 NPL=1,NPLTS
      CALL PLATE(NPL,NCNRS,SEGM,IREC,IPN,IGS,PCN,ICHG)
  420 CONTINUE
C
C                --- REUSE OF IMPEDANCE MATRIX ---
C     Disk storage of impedance is not anticipated; therefore:
  300 IWRZM=0
      IRDZM=0
C
      IF(USEWRS.EQ.'N'.OR.USEWRS.EQ.'n') GOTO 800
C
C                  --- INPUT WIRE INFORMATION ---
      CALL WIRE(NM,NP,NAT,NFPT,NSF1,NSF2,ICHG)
      CALL WRPTS(I,NP,X,Y,Z,ICHG)
      CALL ENDPT(NM,IA,IB,ICHG)
      CALL FPPLT(NFPT,IFM,IABFP,VLG,ZL,ICHG)
C
      DO 700 I=1,NAT
      CALL FPNPL(I,NAS,IABAP,NPLA,VGA,ZLDA,BDSK,ICHG)
  700 CONTINUE
  800 CONTINUE
C
C          --- PARAMETER VALUES WRITTEN TO DATA FILE ---
C
  810 WRITE(10,100)NGO,NPRINT,NRUNS,NWGS,IWR,IWRZT,INT,INTP,INTD,INWR,IR
     1GM,IFIL
      WRITE(10,*) IFE,IPFE,NDFE,PHFE
      WRITE(10,*) IFA,IPFA,NDFA,THFA
      WRITE(10,*) ISE,IPSE,NDSE,PHSE,THIN,PHIN
      WRITE(10,*) ISA,IPSA,NDSA,THSA
      WRITE(10,*) FMC,CMM,A
C
      IF(USEPLT.EQ.'N'.OR.USEPLT.EQ.'n') GOTO 760
C
      WRITE(10,*) NPLTS
C
      DO 750 NPL=1,NPLTS
      WRITE(10,*) NCNRS(NPL),SEGM(NPL),IREC(NPL),IPN(NPL),IGS(NPL)
      DO 725 NCNR=1,NCNRS(NPL)
      WRITE(10,*) PCN(1,NCNR,NPL),PCN(2,NCNR,NPL),PCN(3,NCNR,NPL)
  725 CONTINUE
  750 CONTINUE
      GOTO 770
C
C       --- INPUT FILLER NUMBERS FOR NO-PLATES CASE ---
C
  760 WRITE(10,*) 0
      WRITE(10,*) 4, 0.2, 1, 3, 0
      DO 780 I=1,4
      WRITE(10,*) 1.0, 1.0, 1.0
  780 CONTINUE
C
  770 WRITE(10,*) IWRZM,IRDZM
C
C   --- DO NOT WRITE WIRE INFORMATION TO FILE FOR NO-WIRES CASE ---
      IF(USEWRS.EQ.'N'.OR.USEWRS.EQ.'n') GOTO 1000
C
      WRITE(10,*) NM,NP,NAT,NFPT,NFS1,NFS2
C
      DO 775 I=1,NP
```

```
      WRITE(10,*) X(I),Y(I),Z(I)
  775 CONTINUE
C
      DO 777 I=1,NM
      WRITE(10,*) IA(I),IB(I)
  777 CONTINUE
C
      IF(NFPT.GT.0) GOTO 3000
      WRITE(10,*) 1,0,(1.,0.),(1.,0.)
      GOTO 3100
C
 3000 DO 850 I=1,NFPT
      WRITE(10,*) IFM(I),IABFP(I),VLG(I),ZL(I)
  850 CONTINUE
C
 3100 DO 900 I=1,NAT
      WRITE(10,*) NAS(I),IABAP(I),NPLA(I),VGA(I),ZLDA(I),BDSK(I)
  900 CONTINUE
C
  100 FORMAT(12I5)
 1000 CONTINUE
C
      END
```

```
C
      SUBROUTINE FPNPL(NAT,NAS,IABAP,NPLA,VGA,ZLDA,BDSK,ICHG)
      DIMENSION NAS(10),IABAP(10),NPLA(10),VGA(10),ZLDA(10),BDSK(10)
      IF(NAT.EQ.0) GOTO 800
      DO 700 I=1,NAT
      WRITE(*,655)
  655 FORMAT(/1X,'NUMBER OF WIRE SEGMENT ATTACHED TO PLATE?')
      CALL ICHNGE(NAS(I),0,0,1,ICHG)
      READ(*,*) NAS(I)
      WRITE(*,750)
      WRITE(*,660)
  660 FORMAT(/1X,'ENDPOINT ATTACHED TO PLATE:'/10X,'0  POINT A'/10X,'1   P
     1OINT B')
      CALL ICHNGE(IABAP(I),0,0,1,ICHG)
      READ(*,*) IABAP(I)
      WRITE(*,750)
      WRITE(*,665)
  665 FORMAT(/1X,'PLATE NUMBER?')
      CALL ICHNGE(NPLA(I),0,0,1,ICHG)
      READ(*,*) NPLA(I)
      WRITE(*,750)
      WRITE(*,670)
  670 FORMAT(/1X,'COMPLEX GENERATOR VOLTAGE AT ATTACHMENT POINT?')
      READ(*,*) VGA(I)
      WRITE(*,675)
  675 FORMAT(/1X,'COMPLEX LOAD IMPEDANCE AT ATTACHMENT POINT?')
      READ(*,*) ZLDA(I)
      WRITE(*,680)
  680 FORMAT(/1X,'DISK RADIUS IN METERS?')
      READ(*,*) BDSK(I)
  700 CONTINUE
  750 FORMAT(/)
  800 CONTINUE
      RETURN
      END
```

```
C
      SUBROUTINE FPPLT(NFPT, IFM, IABFP, VLG, ZL, ICHG)
      DIMENSION IFM(10), IABFP(10), VLG(10), ZL(10)
      COMPLEX VLG
      COMPLEX ZL
C
      WRITE(5,560)
  560 FORMAT(/1X,'INPUT LOCATIONS OF FEED POINTS:'/)
      DO 650 I=1,NFPT
      WRITE(5,570) I
  570 FORMAT(1X,'FEED POINT NO.  ',I3)
      WRITE(5,575)
  575 FORMAT(1X,'IN WHICH WIRE SEGMENT?')
      CALL ICHNGE(IFM(I),0,0,1,ICHG)
      READ(5,*) IFM(I)
      WRITE(*,700)
      WRITE(5,580)
  580 FORMAT(1X,'AT WHICH END OF SEGMENT?'/10X,'0  ENDPOINT A'/10X,'1  E
     1NDPOINT B'/)
      CALL ICHNGE(IABFP(I),0,0,1,ICHG)
      READ(5,*) IABFP(I)
      WRITE(*,700)
C
      WRITE(5,590)
  590 FORMAT(/1X,'INPUT COMPLEX VOLTAGE OF GENERATOR AT FEED POINT:')
      READ(5,*) VLG(I)
      WRITE(*,700)
      WRITE(5,600)
  600 FORMAT(/1X,'INPUT COMPLEX LOAD IMPEDANCE (OHMS):')
      READ(5,*) ZL(I)
      WRITE(*,700)
  700 FORMAT(/)
  650 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RCHNGE(R1,R2,R3,N,ICHG)
      IF(ICHG.EQ.0) GOTO 50
      IF(N.EQ.1) WRITE(*,10) R1
      IF(N.EQ.2) WRITE(*,20) R1,R2
      IF(N.EQ.3) WRITE(*,30) R1,R2,R3
10    FORMAT(1X,'THE PRESENT VALUE IS ',F8.2)
20    FORMAT(1X,'THE PRESENT VALUES ARE: '/2F8.2)
30    FORMAT(1X,'THE PRESENT VALUES ARE: '/3F8.2)
      WRITE(*,40)
40    FORMAT(1X,'NEW VALUE(S)?')
50    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ICHNGE(I1,I2,I3,N,ICHG)
      IF(ICHG.EQ.0) GOTO 50
      IF(N.EQ.1) WRITE(*,10) I1
      IF(N.EQ.2) WRITE(*,20) I1,I2
      IF(N.EQ.3) WRITE(*,30) I1,I2,I3
   10 FORMAT(1X,'THE PRESENT VALUE IS ',I5)
   20 FORMAT(1X,'THE PRESENT VALUES ARE: '/2I5)
   30 FORMAT(1X,'THE PRESENT VALUES ARE: '/3I5)
      WRITE(*,40)
   40 FORMAT(1X,'NEW VALUE(S)?')
   50 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PLATE(NPL,NCNRS,SEGM,IREC,IPN,IGS,PCN,ICHG)
      DIMENSION NCNRS(10),SEGM(10),IREC(10),IGS(10),IPN(10),PCN(3,10,10)
      WRITE(5,240) NPL
  240 FORMAT(1X,'PLATE NUMBER ',I3)
      WRITE(5,250)
  250 FORMAT(1X,'HOW MANY CORNERS?')
      CALL ICHNGE(NCNRS(NPL),0,0,1,ICHG)
      READ(5,*)NCNRS(NPL)
      WRITE(*,272)
      WRITE(5,252)
  252 FORMAT(1X,'SIZE OF PATCH?')
      CALL RCHNGE(SEGM(NPL),0.,0.,1,ICHG)
      READ(5,*) SEGM(NPL)
      WRITE(*,272)
      WRITE(5,254)
  254 FORMAT(1X,'IDENTIFY SHAPE OF PLATE -'/10X,'0  POLYGONAL'/10X,'1  R
     1ECTANGULAR'/)
      CALL ICHNGE(IREC(NPL),0,0,1,ICHG)
      READ(5,*) IREC(NPL)
      WRITE(*,272)
C
C        *** POLARIZATION SELECTION IS SET TO 3 FOR ALL CASES ***
      IPN(NPL)=3
C
      WRITE(5,256)
  256 FORMAT(1X,'WHICH IS THE GENERATING SIDE?')
      CALL ICHNGE(IGS(NPL),0,0,1,ICHG)
      READ(5,*) IGS(NPL)
      WRITE(*,272)
C
      WRITE(5,260)
  260 FORMAT(/1X,'INPUT POSITION OF EACH CORNER (X, Y, Z)')
C
      DO 275 NCNR=1,NCNRS(NPL)
      WRITE(5,270) NCNR
  270 FORMAT(1X,'NO.  ',I3)
      CALL RCHNGE(PCN(1,NCNR,NPL),PCN(2,NCNR,NPL),PCN(3,NCNR,NPL),3,ICHG
     1)
      READ(5,*)PCN(1,NCNR,NPL),PCN(2,NCNR,NPL),PCN(3,NCNR,NPL)
      WRITE(*,272)
  272 FORMAT(/)
  275 CONTINUE
      RETURN
      END
```

```
C
      SUBROUTINE WRPTS(I,NP,X,Y,Z,ICHG)
      DIMENSION X(10),Y(10),Z(10)
      WRITE(5,520)
  520 FORMAT(/1X,'INPUT LOCATIONS (X,Y,Z) OF WIRE POINTS: ')
      DO 530 I=1,NP
      WRITE(5,525) I
  525 FORMAT(1X,'POINT ',I3)
      CALL RCHNGE(X(I),Y(I),Z(I),3,ICHG)
      READ(5,*) X(I),  Y(I),  Z(I)
      WRITE(*,600)
  530 CONTINUE
  600 FORMAT(/)
      RETURN
      END
```

```
C
      SUBROUTINE WIRE(NM,NP,NAT,NFPT,NSF1,NSF2,ICHG)
      WRITE(5,430)
  430 FORMAT(/1X,'NUMBER OF WIRE SEGMENTS?')
      CALL ICHNGE(NM,0,0,1,ICHG)
      READ(5,*) NM
      WRITE(*,600)
      WRITE(5,440)
  440 FORMAT(1X,'TOTAL NUMBER OF POINTS IN THE WIRE STRUCTURE?')
      CALL ICHNGE(NP,0,0,1,ICHG)
      READ(5,*) NP
      WRITE(*,600)
      WRITE(5,450)
  450 FORMAT(1X,'NUMBER OF WIRE-TO-PLATE ATTACHMENT POINTS?')
      CALL ICHNGE(NAT,0,0,1,ICHG)
      READ(5,*) NAT
      WRITE(*,600)
      WRITE(5,460)
  460 FORMAT(1X,'NUMBER OF FEED POINTS IN THE WIRE STRUCTURE?')
      CALL ICHNGE(NFPT,0,0,1,ICHG)
      READ(5,*) NFPT
      WRITE(*,600)
      WRITE(5,470)
C
  470 FORMAT(1X,'IS MUTUAL COUPLING TO BE COMPUTED?')
      READ(5,50) MCOUPL
   50 FORMAT(A1)
      IF(MCOUPL.EQ.'Y'.OR.MCOUPL.EQ.'y') GOTO 480
      NSF1=0
      NSF2=0
      GOTO 510
C
  480 WRITE(5,490)
  490 FORMAT(/1X,'LOCATION OF FIRST FEED PORT?')
      CALL ICHNGE(NSF1,0,0,1,ICHG)
      READ(5,*) NFS1
      WRITE(*,600)
      WRITE(5,500)
  500 FORMAT(1X,'LOCATION OF SECOND FEED PORT?')
      CALL ICHNGE(NSF2,0,0,1,ICHG)
      READ(5,*) NFS2
      WRITE(*,600)
  600 FORMAT(/)
  510 CONTINUE
      RETURN
      END
```

```
C
      SUBROUTINE ENDPT(NM, IA, IB, ICHG)
      DIMENSION IA(10), IB(10)
      WRITE(5, 535)
  535 FORMAT(/1X, 'INPUT ENDPOINT A & ENDPOINT B OF EACH WIRE SEGMENT: '/)
      DO 550 J=1, NM
      WRITE(5, 540) J
  540 FORMAT(1X, 'SEGMENT ', I3)
      CALL ICHNGE(IA(J), IB(J), 0, 2, ICHG)
      READ(5, *) IA(J),  IB(J)
      WRITE(*, 600)
  550 CONTINUE
  600 FORMAT(/)
      RETURN
      END
```